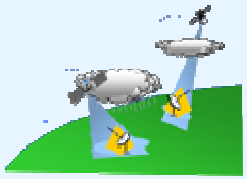
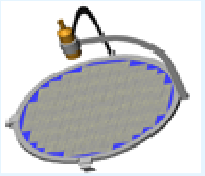
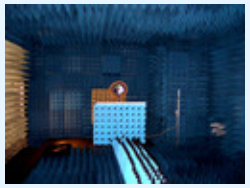
Antenna Technology and other Radio Frequency (RF) Communications Activities at the Glenn Research Center in Support of NASA's Exploration Vision



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NASA Glenn Research Center, Cleveland, OH 44135

Penn State University
January 30, 2007

ABSTRACT

NASA's Vision for Space Exploration outlines a very ambitious program for the next several decades of the Space Agency endeavors. Ahead is the completion of the International Space Station (ISS); safely flight the shuttle (STS) until 2010; develop and fly the Crew Exploration Vehicle (Orion) by no later than 2014; return to the moon by no later than 2020; extend human presence across the solar system and beyond; implement a sustainable and affordable human and robotic program; develop supporting innovative technologies, knowledge and infrastructure; and promote international and commercial participation in exploration.

To achieve these goals, a series of enabling technologies must be developed or matured in a timely manner. Some of these technologies are: spacecraft RF technology (e.g., high power sources and large antennas which using surface receive arrays can get up to 1 Gbps from Mars), uplink arraying (reduce reliance on large ground-based antennas and high operation costs; single point of failure; enable greater data-rates or greater effective distance; scalable, evolvable, flexible scheduling), software define radio (i.e., reconfigurable, flexible interoperability allows for in flight updates open architecture; reduces mass, power, volume), and optical communications (high capacity communications with low mass/power required; significantly increases data rates for deep space).

This presentation will discuss some of the work being performed at the NASA Glenn Research Center, Cleveland, Ohio, in antenna technology as well as other on-going RF communications efforts.

Outline of Presentation

- The Vision for Space Exploration
- Enabling Technologies
- Existing NASA Communications Capabilities
- Communications Architecture for Exploration
- Asset-Specific Communications Requirements
- Communications at GRC:
  - Relevant Antenna Technologies
  - Other RF Technologies
- Conclusions

A Bold Vision for Space Exploration

NASA's Vision for Space Exploration outlines a very ambitious program for the next several decades of the Space Agency endeavors. Ahead are the following milestones:

- Completion of the International Space Station (ISS)
- Safely flight the shuttle (STS) until 2010
- Develop and fly the Crew Exploration Vehicle (Orion) by no later than 2014
- Return to the moon by no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustainable and affordable human and robotic program
- Develop supporting innovative technologies, knowledge and infrastructure
- Promote international and commercial participation in exploration.

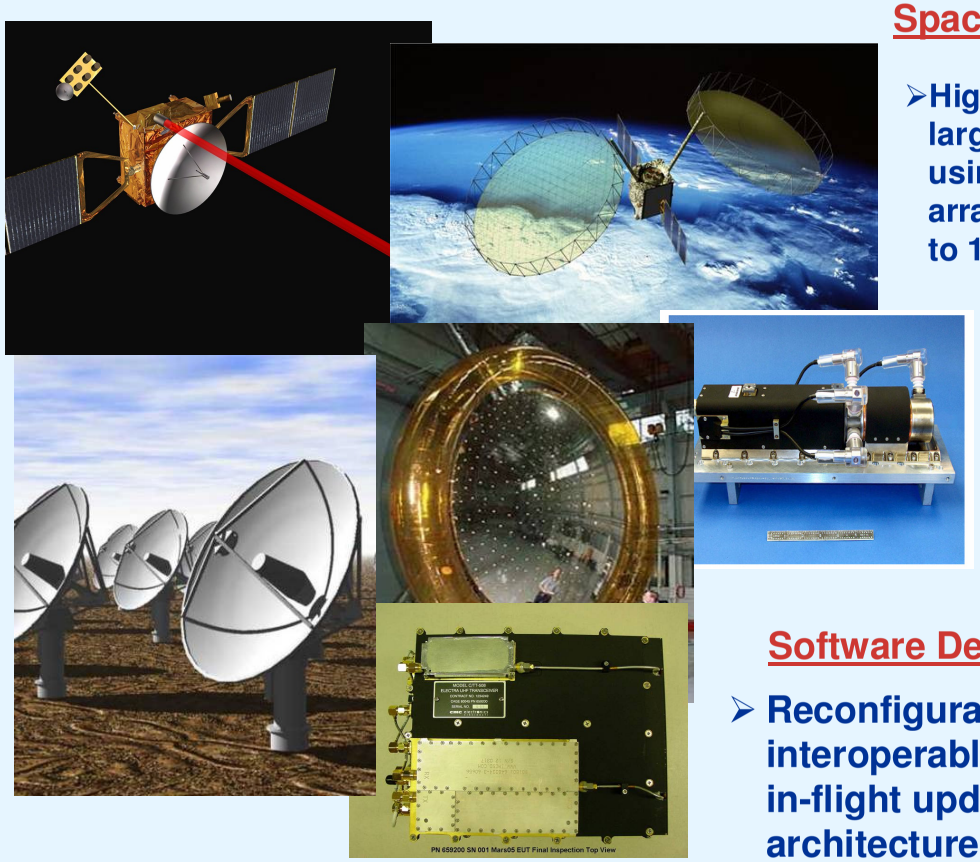
Enabling Technologies

Optical Communications

- High capacity comm with low mass/power required
- Significantly increase data rates for deep space

Uplink Arraying

- Reduce reliance on large antennas and high operating costs, single point of failure
- Scalable, evolvable, flexible scheduling
- Enables greater data-rates or greater effective distance



Spacecraft RF Technology

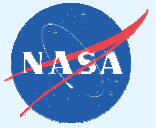
- High power sources, large antennas and using surface receive array can get data rates to 1Gbps from Mars

Software Defined Radio

- Reconfigurable, flexible, interoperable allows for in-flight updates open architecture.
- Reduce mass, power, vol.

Assessment of Existing NASA Communications Capability

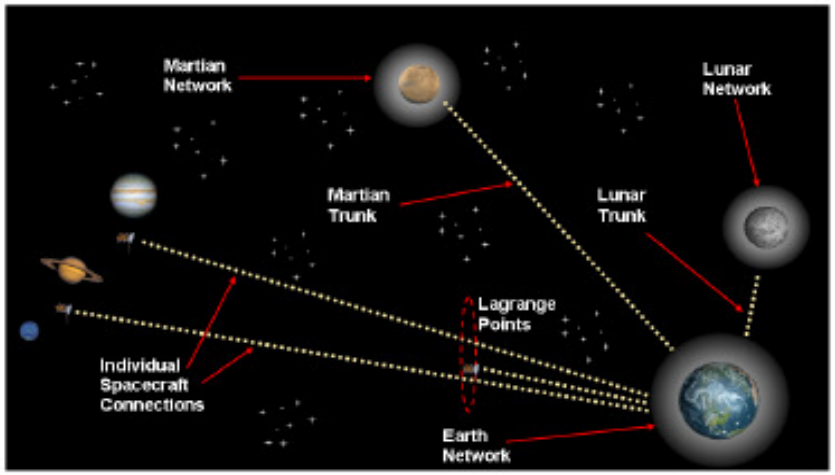
- Limited lunar coverage
- Existing Earth-based Tracking and Data Relay Satellite System (TDRSS) can presently provide limited Low Earth Orbit (LEO) and translunar backup systems for critical communications in lunar vicinity due to area coverage limitations
- Ground Networks (GN) can provide LEO and translunar short pass duration communications
- Large aperture Deep Space Network (DSN) antennas (26m, 34m, 70m) can provide excellent high-rate coverage in lunar vicinity
- Limited Mars communications data rates and numbers of connections
- Limited precision Mars navigation capability



Communications Architecture

Space Communication Architecture Working Group (SCAWG)

NASA Space Communication and Navigation Architecture Recommendations for 2005-2030



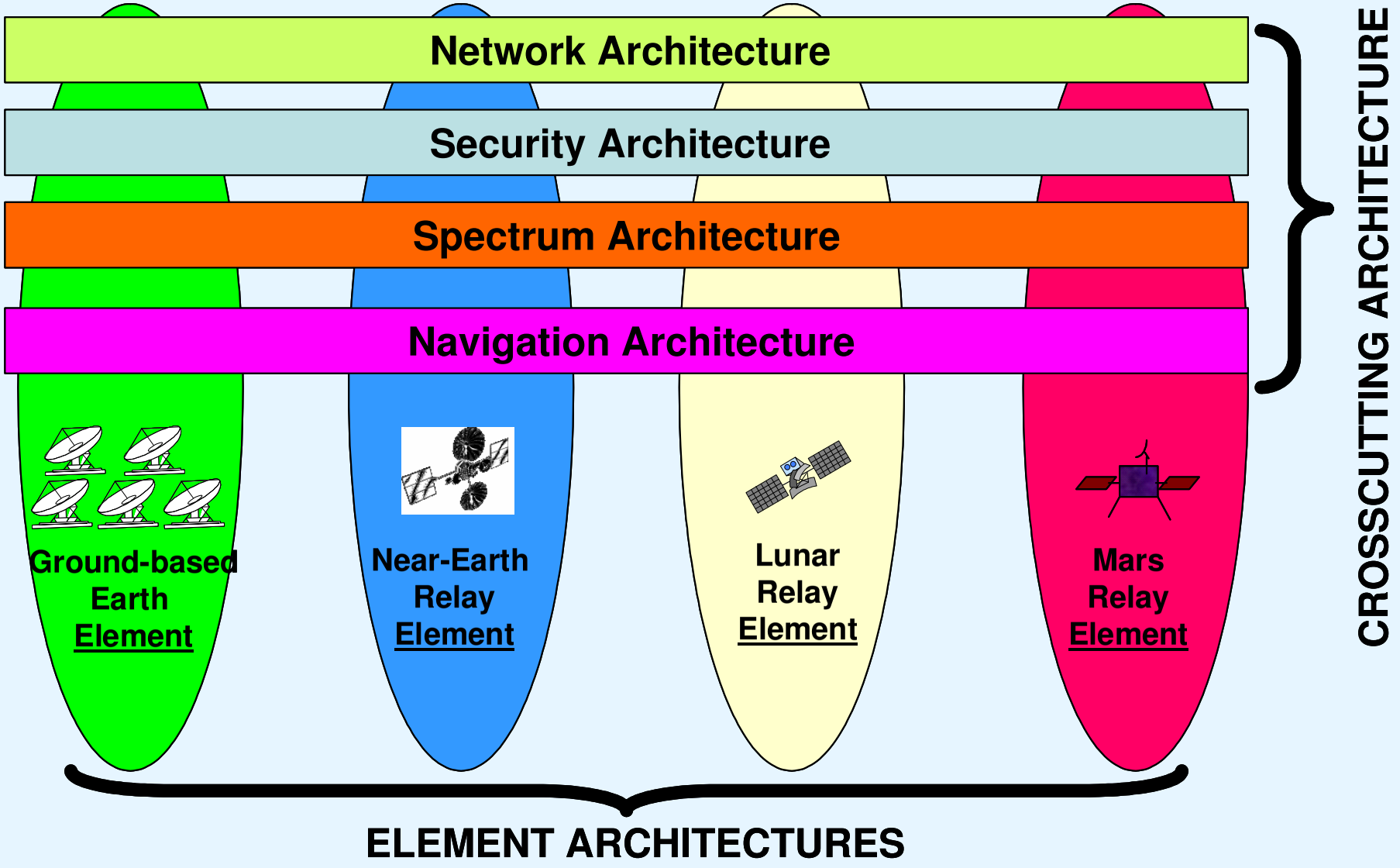
15 May 2006

Final Report

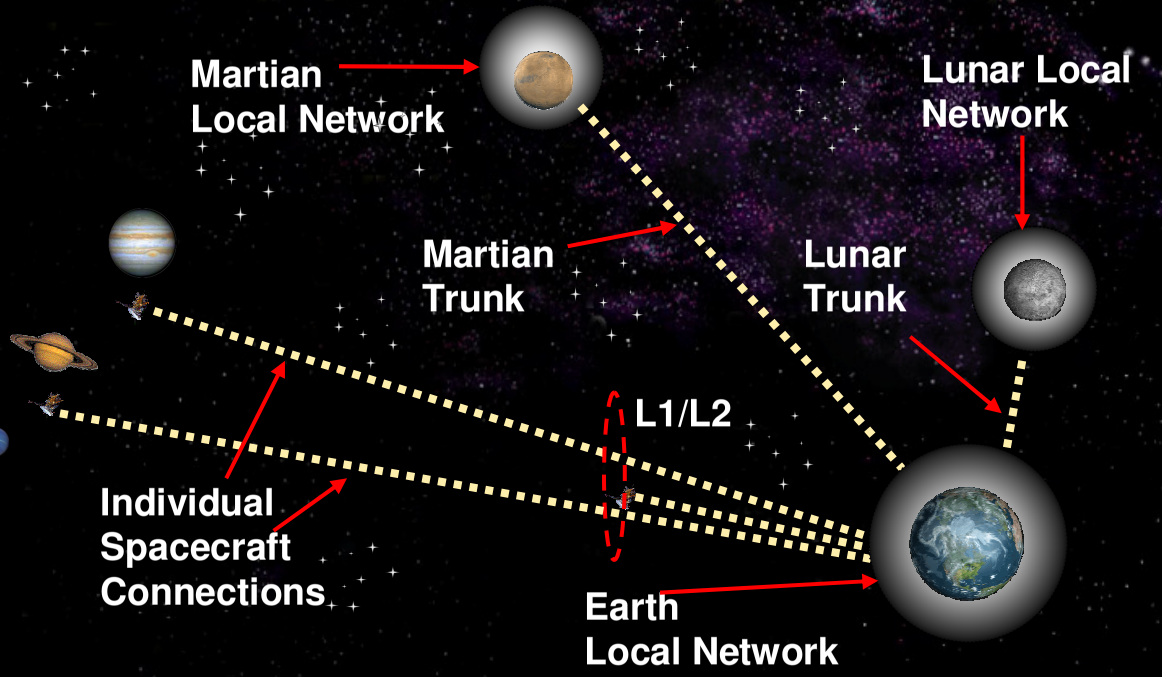
Space Communications Architecture Final Report is available.

https://www.spacecomm.nasa.gov/spacecomm/

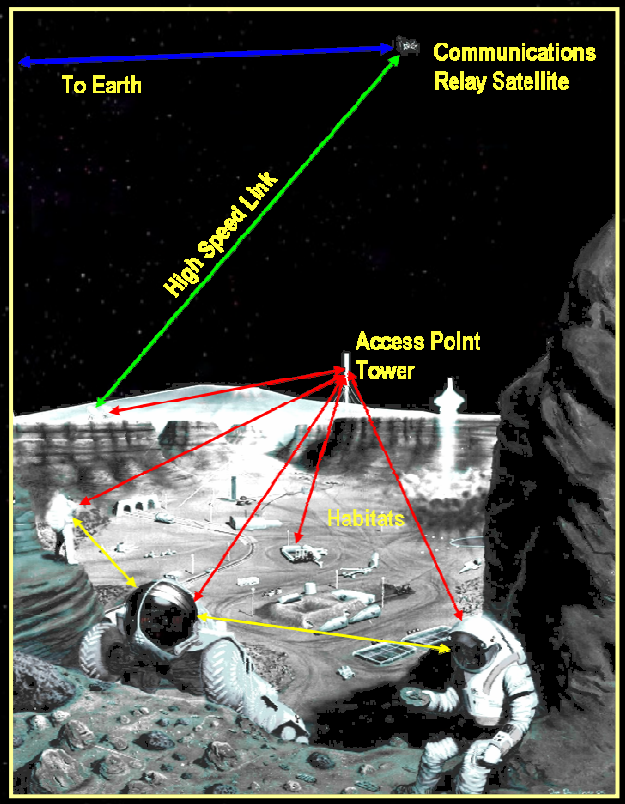
Communications Architecture



Communications Network Architecture



Top Level Conceptual Communication Architecture ~2030: A "network of networks"

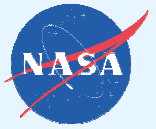


Communications architecture on the Lunar Surface

Ref: C. James S. Schier, John J. Rush, W. Dan Williams, and Pete Vrotsos, "Space Communication Architecture Supporting Exploration and Science: Plans and Studies for 2010-2030," AIAA 1st Space Exploration Conference, Jan. 2005.

Ref 2: Final Report Space Communications Architecture Working Group (SCAWG): NASA Space Communications and Navigation Architecture Recommendations for 2005-2030, 15 May 2006.

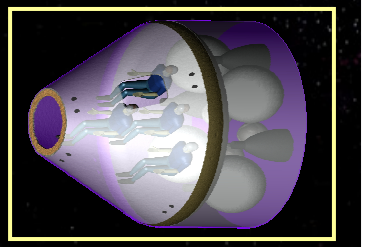
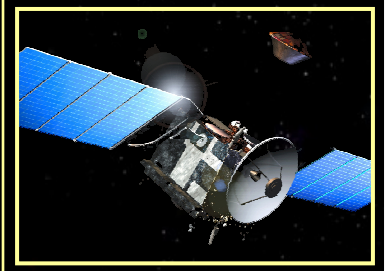
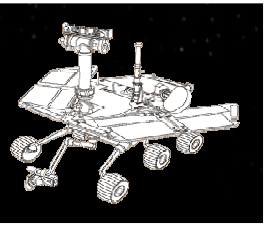
Ref: CRAI/APIO Roadmap Team, "Communication and Networking for Space Missions," Joint Workshop, Sec. 2.1, Sept. 2004.



Asset-Specific Communications Nominal Specifications

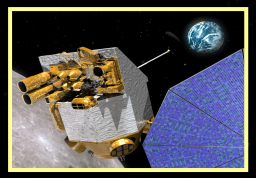
Antenna Technology Summary

Space Communication Assets

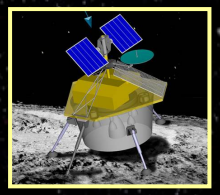
Surface/Orbit Communications	Potential Frequencies	Comments/Specs	Desirable Antenna Technologies
CEV 	S-band X-band Ku/Ka-band	➢ Robotic Lunar Exploration Program (RLEP-1,2) ➢ Lunar Reconnaissance Orbiter (LRO) (RLEP-1) ➢ Crew Launch Vehicle (CLV) ➢ Crew Exploration Vehicle (CEV) ➢ *Antenna Requirements: Conformal, Reconfigurable or Multiband antennas, phased arrays (most likely S-band for Initial CEV, with omni or patch antennas).*	➢ Phased Arrays ➢ Wideband/multiband and conformal antennas ➢ Frequency selective surface (FSS) antennas
Satellites Systems 	UHF S-band X-band Ku/Ka-band	➢ Relay satellites (around the moon (e.g., LRO after its initial prospecting mission, it could be elevated to elliptical orbit for relay purposes); around Mars; etc.) ➢ Relay satellites (L1/L2) ➢ The intended orbit will drive the type of antenna technology. ➢ *In Orbit: Gimbaled dish? (slew rate driven), reflectarrays, phased array antennas, deployable/inflatable arrays*	➢ Gimbaled Dish ➢ Phased Arrays ➢ Deployable Antennas ➢ Multi-Beam antennas ➢ High Gain Antennas
Rovers 	UHF S-band	➢ Mobile Nodes with data-intensive mission requirements for surface-based exploration. ➢ Characterized by entities of moderate size and free to move about the lunar surface (e.g., rovers, pressurized vehicles, astronauts, robots) ➢ Tightly constrained by power, mass and volume.	➢ Miniaturized antennas ➢ Phased Arrays
	UHF	➢ Small Nodes: support fixed and mobile nodes, and connect to the network by wired or wireless interface. ➢ Sensors, small probes, instruments and subsystems of very small size, limited power levels, and short range (~10 m) low data rate communications. ➢ *Antennas should be low/self-powered, small, and efficient.*	➢ Miniature Antennas ➢ Solar Cell Integrated ➢ Antennas ➢ Patch antennas ➢ Retro-directive antennas

Lunar and Mars Communications Assets

Lunar Network

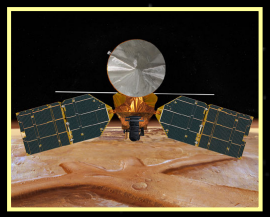


Lunar Reconnaissance Orbiter (LRO)



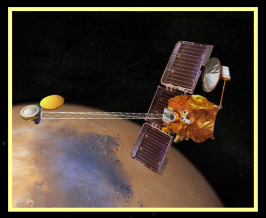
Robotic Lunar Lander

Martian Network



Mars Reconnaissance Orbiter (MRO)

Arrival Date: March 10, 2006

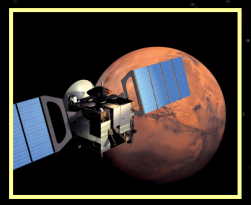


Mars Odyssey

Arrived October 24, 2001

Mars Global Surveyor (MGS)

Arrived September 12, 1997



Mars Express (ESA)

Arrived December 25, 2003

Characteristics of Communication Assets for the Lunar and Martian Networks

Communications Asset	Frequencies	Data Rates	Purpose
The Moon			
Lunar Reconnaissance Orbiter	S-band	125 to 256 bps	TT&C/Rx from Earth
	UHF/S-band	125 to 256 bps	Tx/Rx to Moon
	Ka-band	> 100 Mbps	Tx to Earth
Robotic Lunar Exploration Landers	S-band/Ka-band	TBD	Tx/Rx to Earth
	UHF	TBD	Surface Comm.
Mars			
Mars Reconnaissance Orbiter	X-band	300 kbps	Tx/Rx to Earth
	UHF	0.1 to 1 Mbps	Tx/Rx to Mars
	Ka-band	5 Mbps	Tx to Earth
Mars Global Surveyor	X-band	20 kbps	Tx/Rx to Earth
	UHF	128 kbps	Tx/Rx to Mars
	Ka-band	85 kbps (max)	Tx to Earth
Mars Express (ESA)	X-band	230 kbps	Tx to Earth
	S-band	< 2 kbps	Rx from Earth
	UHF	128 kbps	Tx/Rx to Mars
Mars Odyssey	X-band	128 kbps	Tx/Rx to Earth
	UHF	128 kbps	Tx/Rx to Mars

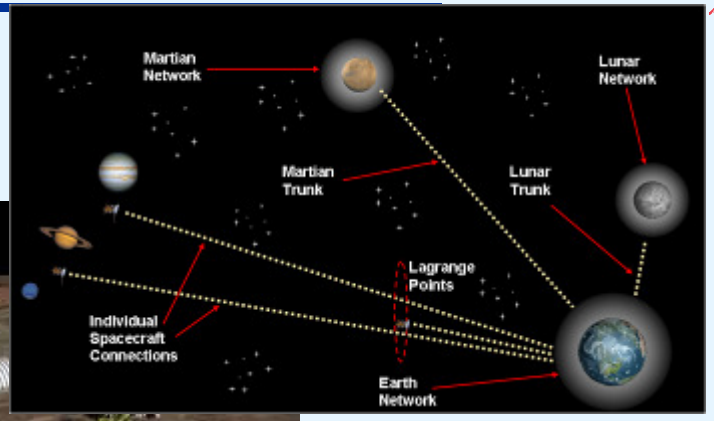
Antenna Technology Summary

Surface Communications Assets

Surface/ Surface Communications	Potential Frequencies	Comments/Specs	Desirable Antenna Technologies
Astronaut EVA Suit 	**UHF/VHF** **S-band**	**Data Services** **Audio** 8-64 kbps/channel (at least 4 channels) **TT&C*** <100 Kbps **SDTV Video** 6 Mbps **HDTV Video** 19 Mbps **Biomedical Control*** 70 kbps **Biomedical Monitoring*** 122 kbps **Limited power/space availability ; UHF/S-Band surface comm. frequencies** ***Must be reliable links** ➢ Reliable links require low BER ➢ ***Antennas should be small, efficient and wideband/multiband to accommodate desired frequencies and data services in a restricted space.*** ➢ ***Multiband important for Software Defined Radio (SDR) to reduce size, weight and power (SWaP)***	• Miniature Antennas • Multi-directional (to support mobility) • Wearable Antennas • Dipole/Monopole (omni-directional coverage)
	UHF/VHF **S-band**	➢ Mobile Nodes with data-intensive mission requirements for surface-based exploration. ➢ Characterized by entities of moderate size and free to move about the lunar surface (e.g., rovers, pressurized vehicles, astronauts, robots) ➢ Tightly constrained by power, mass and volume. ➢ ***Antennas should be low/self-powered, small, and efficient, and compatible with communication equipment that can provide high data rate coverage at short ranges (~1.5-3 km, horizon for the moon for EVA).***	• Miniature Antennas • Omni antennas • Phased Arrays (pitch/roll compensation)
	UHF/VHF **S-band**	➢ Small Nodes: support fixed and mobile nodes, and connect to the network by wired or wireless interface. ➢ Sensors, small probes, instruments and subsystems of very small size, limited power levels, and short range (~10 m) low data rate communications. ➢ ***Antennas should be low/self-powered, small, and efficient.***	• Miniature Antennas • Dielectric Resonator Antennas • Wideband Antennas • Solar Cell Integrated Antennas ▪Retro-directive Antenna
Habitat/Surface Relays 	**HF (OTH Propagation)** **S-band** **X-band**	➢ Large, fixed nodes: Serves as base for surface activities. ➢ Centralized Hub/Habitat for immediate area coverage ➢ Transmission of data to surface and space assets ➢ Can support larger communication hardware and higher data rates over long distances. ➢ ***Smart/reconfigurable antennas, multibeam antennas, lightweight deployable antennas are viable technologies (10-30 Km)***	• Deployable Antennas • Multi-directional coverage (to support mobility) • Smart/reconfigurables • Multi-beam antennas (to support connectivity to different nodes) • Electrically & physically small antennas

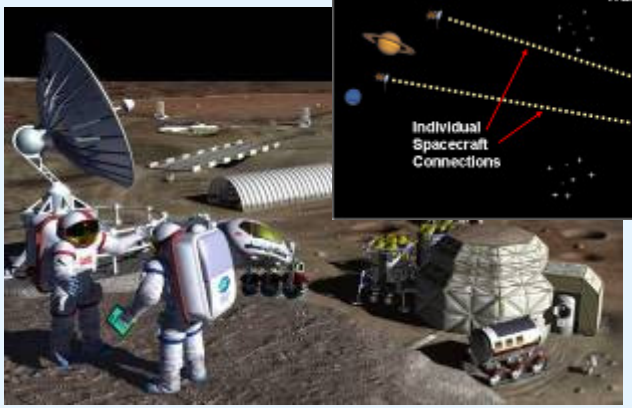
Communications at GRC

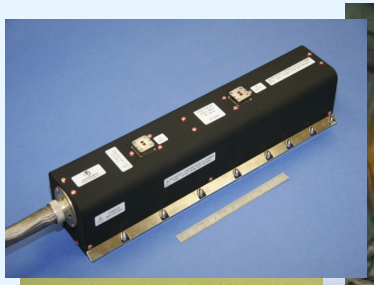
Space Communications Architecture

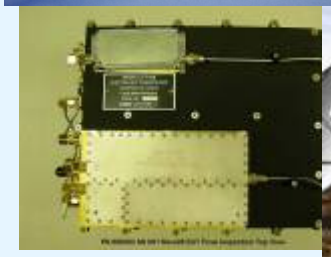


Technologies

- **Network technology**
- **Spacecraft RF Technology**
- **Software Defined Radio**
- **Uplink Arraying**

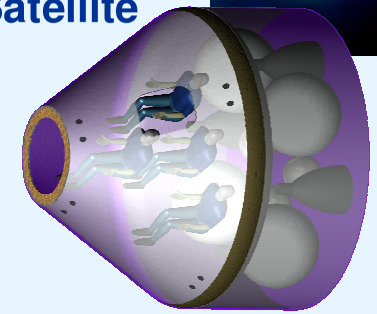


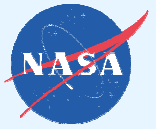




Spacecraft

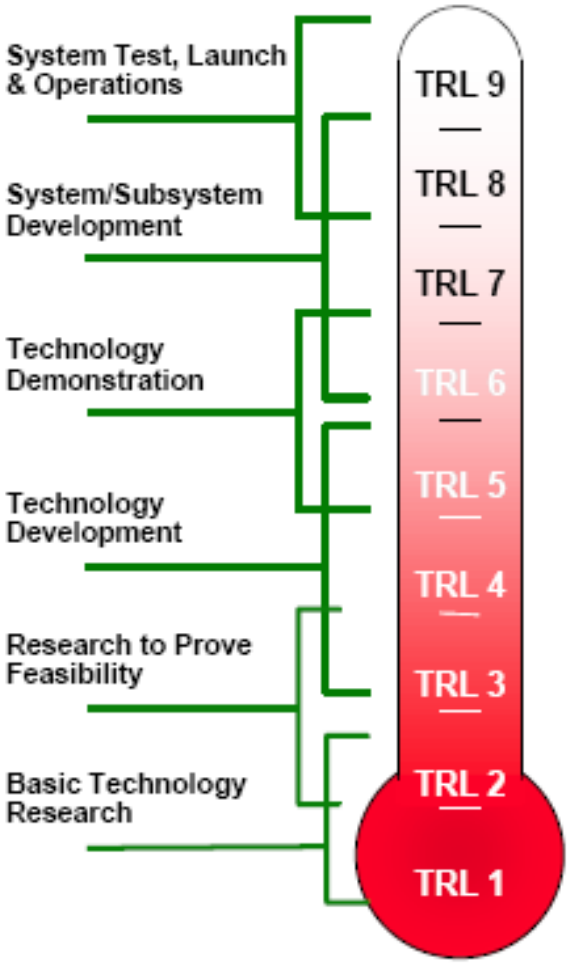
- **Advanced Communications Technology Satellite**
- **CEV**





Relevant Antenna Technologies

Technology Readiness Level



TRL 9 — Actual system "flight proven" through successful mission operations

TRL 8 — Actual system completed and "flight qualified" through test and demonstration (Ground or Flight)

TRL 7 — System prototype demonstration in a space environment

TRL 6 — System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)

TRL 5 — Component and/or breadboard validation in relevant environment

TRL 4 — Component and/or breadboard validation in laboratory environment

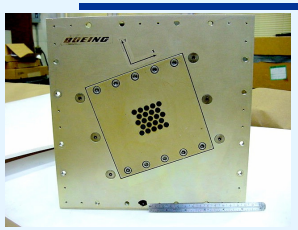
TRL 3 — Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2 — Technology concept and/or application formulated

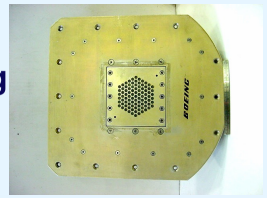
TRL 1 — Basic principles observed and reported

GRC Antenna Research Heritage

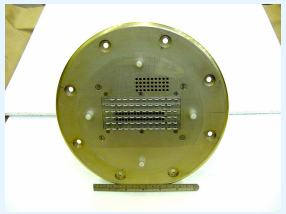
Rcv Array / Boeing
20 GHz (MASCOM)



Xmt Array / TI
30 GHz



Rcv Array / Boeing
20 GHz (ICAPA)

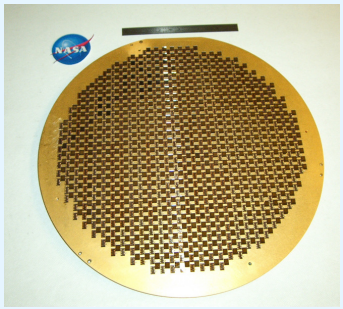


Rcv Array / Martin
20 GHz

Rcv/Xmt Array
AATT/WINCOM
Ku-Band / Boeing

Multibeam
Antenna

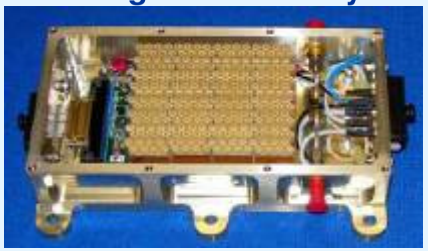
Space Fed Lens
Array EO-1 in
Collaboration with
GSFC



Reflectarray Antenna
SCDS 615 Element
Prototype + Ka-Band
Space Qualifiable

TDRS C Candidate
Cup Waveguide

Ka-band 256 Element
Boeing Phased Array



Shape
Memory
Polymer
Reflector

Large
Inflatable
Gossamer
Antennas

Phased Array Prototypes Technology Demonstrations, and SATCOM On-The-Move

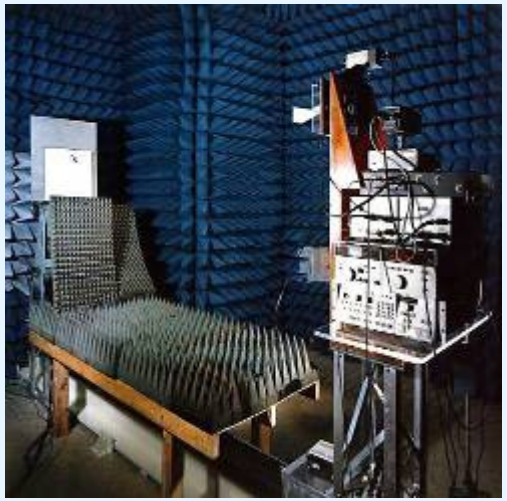
Advanced Phased Array Concepts and Materials + Large Gossamer Deployable Antennas

Space Quality Phased Arrays, Deployable Antennas with Articulated Feeds, Space Experiments, Lunar and Mars Exploration and Earth Science

1990's **2000** **2020**

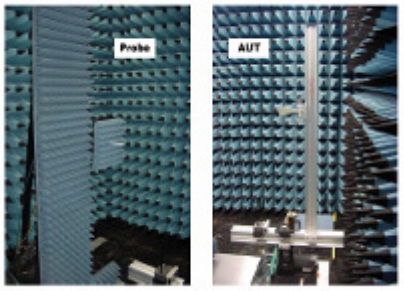
GRC CHARACTERIZATION ANTENNA FACILITIES

Compact Range



Far-Field Range

Near- Field Range



Cylindrical Near- Field Range

http://gltrs.grc.nasa.gov/cgi-bin/GLTRS/browse.pl?2002/TM-2002-211883.html

GRC ANTENNA FACILITIES

Near Field Range

- Measurement of Mechanically Large Microwave Antennas
- 40’ x 40’ x 60’ Test Volume
- 6.7m x 6.7m Vertical Scan Plane
- 15 ton Capacity AZ/EL Positioner
- Removable Sidewall, Bridge Cranes and Loading Ramp Assist Setup
- Frequency range: 2-40 GHz
- Max. Antenna Size: 4-6 m

Far Field Range

- Measurement of small microwave antennas
- 18’x12’x30’ Anechoic Chamber Test Volume
- Frequency Range: 2-40 GHz
- Max. Antenna Size: 1 ft

Cylindrical Near Field Range

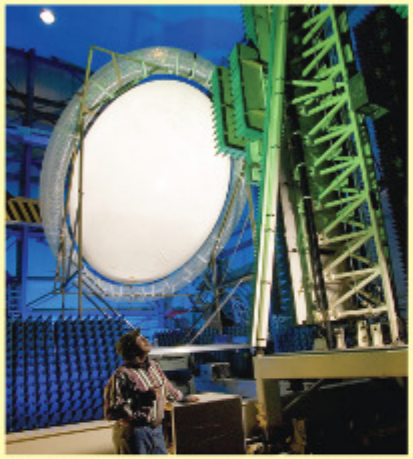
- Measurement of small microwave antennas
- 10’x11’x9’ Anechoic Chamber Test Volume
- NSI 600C-5 Cylindrical Near-Field Scanner System
- Frequency Range: 2-40 GHz
- Max Antenna Size: 10 in

Compact Range

- Antenna and RCS Measurements
- 12’ x10’ x 26’ Anechoic Chamber Test Volume
- 6’x6’ cross section, offset parabolic reflector, 3’x6’ cylindrical quiet zone.
- Frequency range: 2-36 GHz
- Max. Antenna Size: 3ft

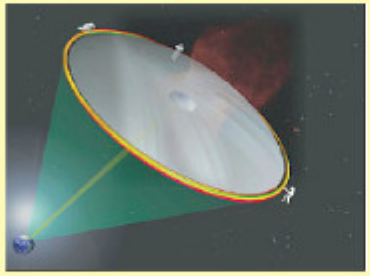
Large Aperture Inflatable Antennas

Space Applications



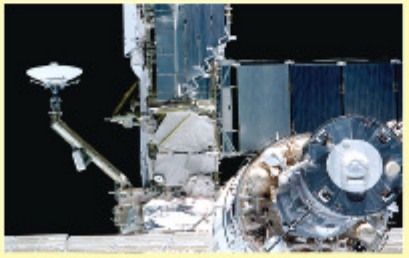
4- by 6-m inflatable offset parabolic membrane antenna test in GRC near-field facility

4- by 6-m inflatable offset parabolic membrane antenna inflation test (human in the background)



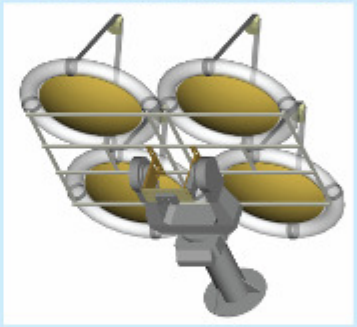
Deep-space relay station concept

Overhead photograph of 4- by 6-m inflatable reflector in GRC near field facility

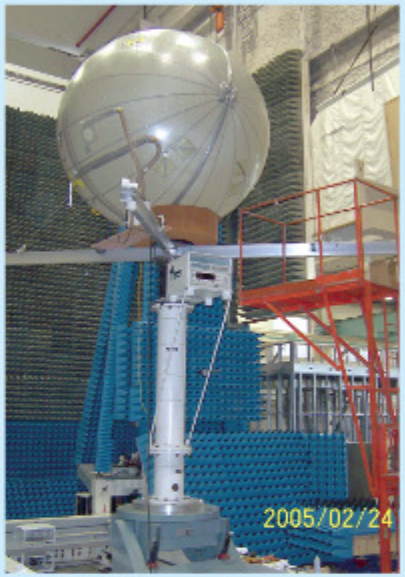


Backup 2-m inflatable Cassegrain reflector for ISS Ku-band system

Surface Applications



Low-cost tracking ground station experiment in collaboration with Goddard Space Flight Center planned for May 2005



2.5-m inflatable membrane antenna in inflatable radome for ground applications

Goals:

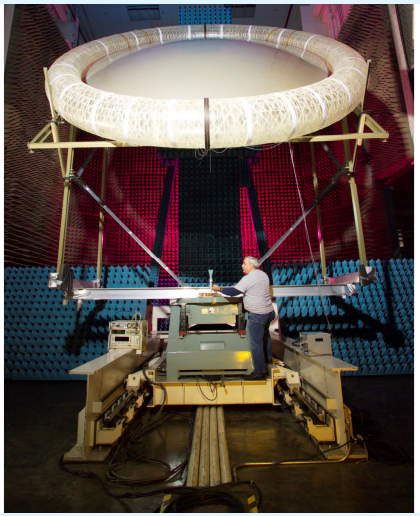
- Develop large, lightweight reflector antennas with areal densities <0.75 kg/m^2, for Lunar, Mars, and deep-space relay exploration applications.
- Develop rigidization techniques (e.g., ultraviolet curing) to eliminate the need for makeup inflation gas.
- Demonstrate a ratio package to deploy volume greater than 1:75.
- Demonstrate quick deployment of large apertures for ground-based and planetary surface applications.

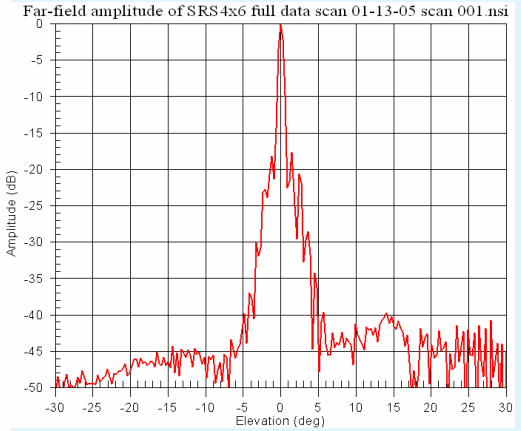
Inflatable Membrane Antenna

PI: Robert Romanofsky

Description and Objectives:

- Evolve gossamer antenna technology to at least TRL 5 at Ka-band in a timely fashion to impact deep-space comm (e.g., Jupiter relay satellite), Exploration (e.g., Mars Aerostationary satellite), ISS Ku-Band link, and Science missions
- Use inflatable membrane technology to demonstrate lower cost, higher reliability and superior performance compared to inflatable reflectarrays and deployable mesh-type reflectors
- Not an approximation to a parabolic surface but optical surface finish and true paraboloid
- Challenges:
  - λ/30 surface accuracy at 32 GHz
  - On-orbit rigidization
  - Thermal environment





Approach:

- Develop inflatable membrane reflectors with high surface accuracy (< 0.5 mm), extremely high packaging efficiency (~50:1) and ~1 kg/m2 aerial density
- Validate basic concept by constructing 1 to 4 meter class engineering models and characterize at X- and Ka-band
- Develop practical rigidization method (e.g. UV cure)
- Demonstrate deployment and shape accuracy in thermal-vacuum environment

Co-I's / Partners:

- LaRC
- SRS Technologies
- AFRL (Edwards)

Milestones and Schedule:

	Target	Status
• 4x6 m membrane reflector	2nd Qtr 05	Complete 2nd QTR 05
• 2.4 m Cassegrain	3rd Qtr 06	3rd Qtr 06
• Ambient rigidized 1 m	3rd QTR 07	
• Rigidization Thermal-Vacuum	4th QTR 08	
• Inflatable Radome System	2nd QTR 10	

Application / Mission:

- Mars Relay satellite
- Science missions at L1, etc.
- ISS Ku-band replacement
- Portable quick-deployment lunar and Mars ground stations
- All deep-space missions requiring high data rate links

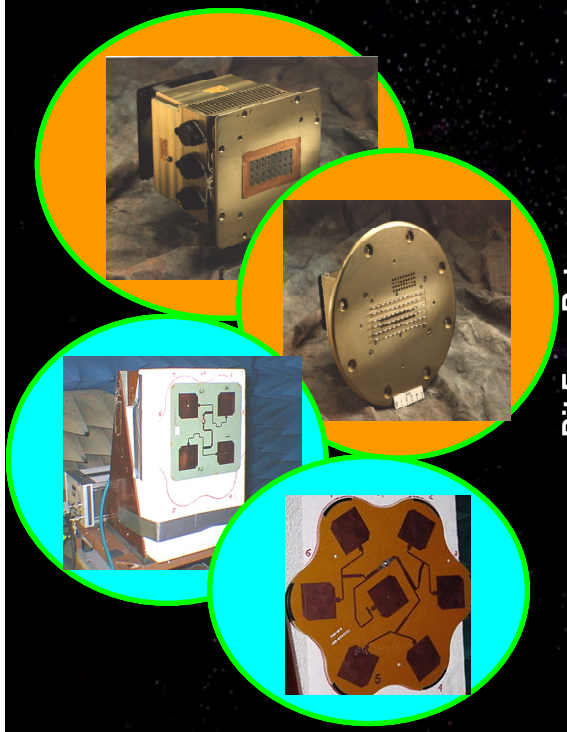
$TRL_{in} = 3$
$TRL_{out} = 5$

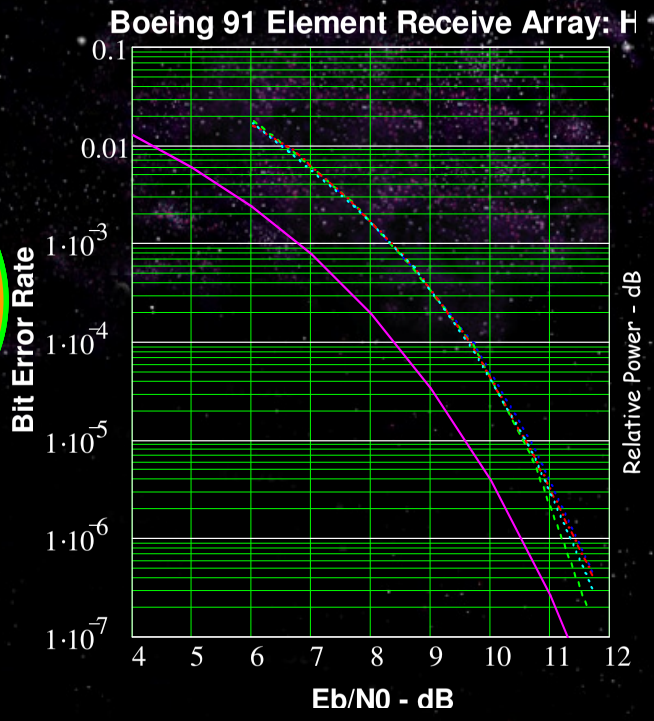
4 Element Inflatable Antenna Array
August 2005

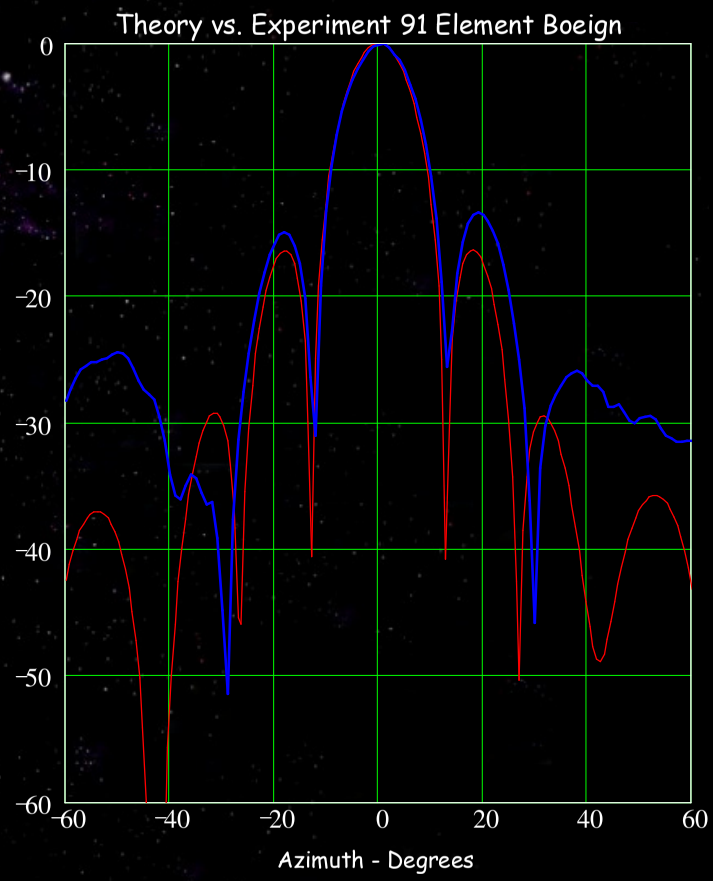
Georgia Tech "GCATT" building adaptive array algorithm verification Experiment with the SAC-C satellite August 22-25, 2005

Phased Array Antennas

(K-, and Ka-Band: TRL 9)







Benefits

- Electrically Steerable
- Conformal
- Graceful degradation
- Multi-Beam
- Fast Scanning/acquisition
- S-, X-, Ku-, K-, and Ka-Band

Issues

- Low MMIC efficiency (thermal management problems)
- Cost per module
- FOV (limited to +/- 60°)

Potential Applications

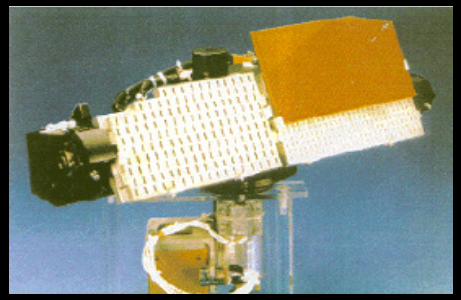
- CLV, CEV
- Robotic Rovers
- Satellite Systems
- Surface Communications

GRC Low Cost Electrically Steerable Array Antenna Road Map

1990 - 1998

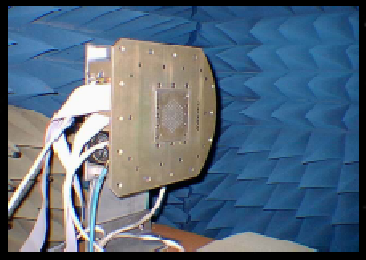
2000 - 2006

Past Significant GRC Ka-band phased array developments

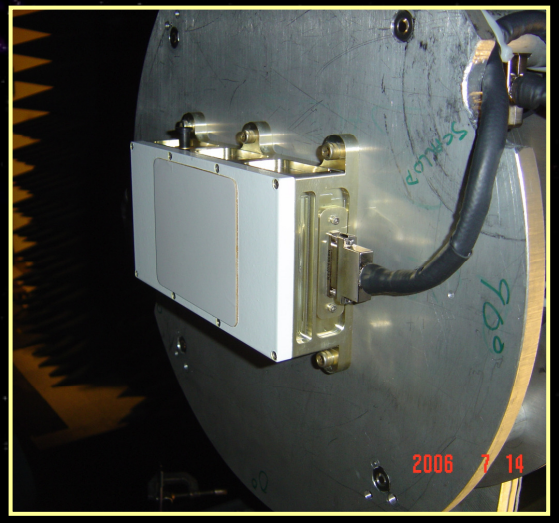


Mechanically steered Array proof-of-concept

32 element breadboard proof-of-concept



91 element breadboard proof-of-concept

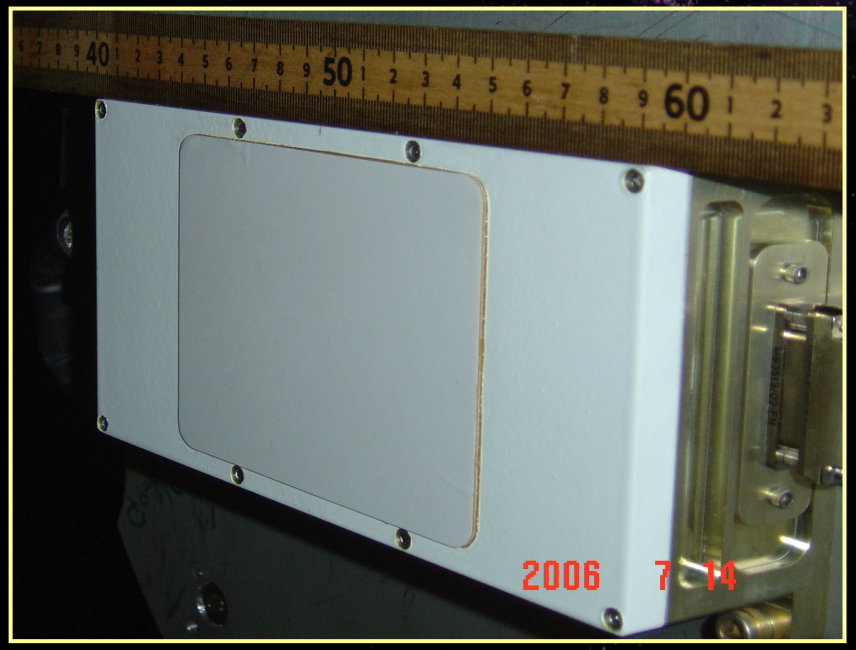


Parameter	Forward Link	Return Link
Ka-band Frequency Plan	30	20
Channel Bandwidth	9.6Kbps (NB) 1.5Mbps (WB)	9.6 – 128 Kbps (NB) 1.5Mbps (WB)

Parameter	Forward Link	Return Link
Ka-band Frequency Plan	22.555 – 23.545	25.545 – 27.195
Channel Bandwidth	50 MHz	650 MHz

- 1990-1998 : Funding Source ACTS
- 2000-2003 : Funding Source SCDS

256-Element Ka-Band Phased Array Antenna (PAA)



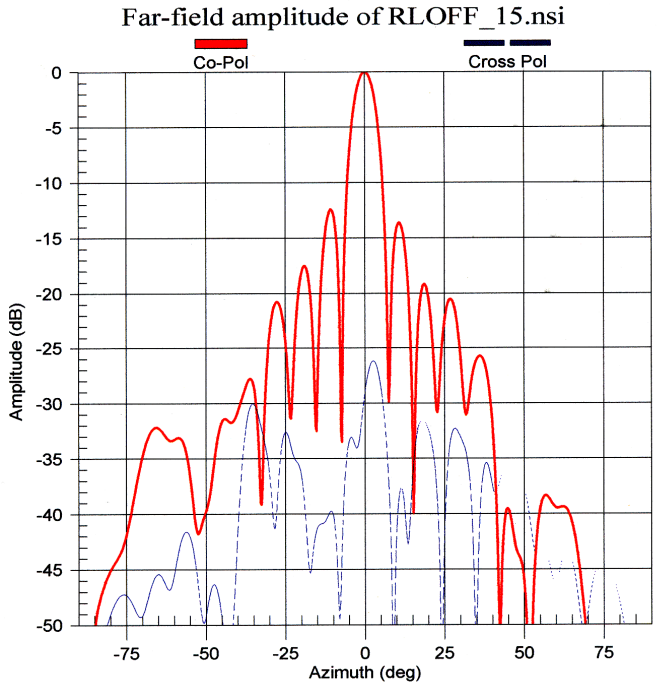
256 Elements Array (Boeing)

Summary Array Specification (Boeing)

Array Number of Elements	256 Elements
Frequencies	25.5-27.5 GHz
Bandwidth	> 1 GHz
Gain (CP)	28 dBi
Antenna EIRP	Peak 36.5 dBW @ 60 Degrees 33 dBW
Antenna 3 dB - Beam width	Nominal 5 Degrees
RF Input Drive Level	130 mW (1 beam)
Array Total DC Power	90 Watts (1 beam)
DC Power Supply	+28 V (± 7V)

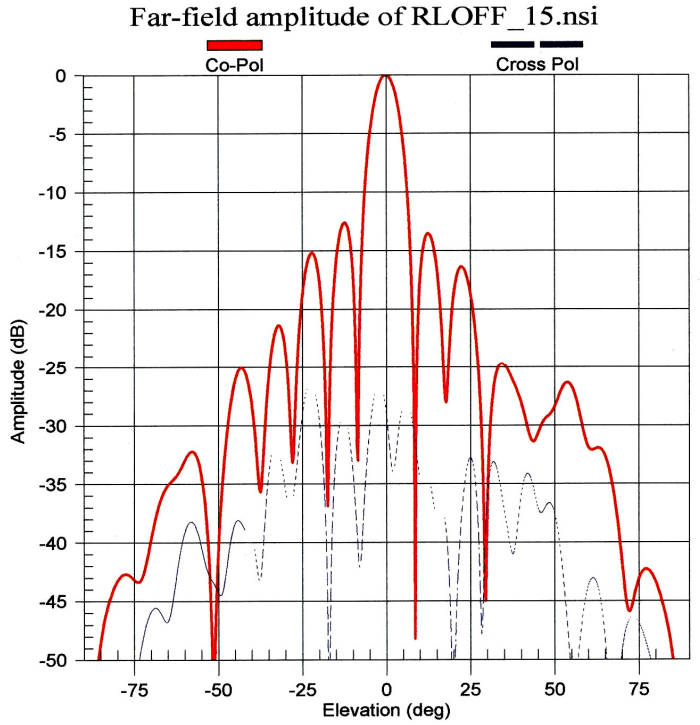
Two Principal Planes Cuts Antenna
(Beam 1)

LHCP w/RHCP off, phi = 0 (Measured by Boeing)



- AR < 1.1
- Directivity (estimated from pattern measurements) : 27.6 dBi
- Directivity (predicted no M-coupling) : 28.2 dBi
- Beamwidth: 6.7 deg

LHCP w/RHCP off, phi = 90 (Measured by Boeing)



- AR < 1.1
- Directivity (estimated from pattern measurements) : 27.6 dBi
- Directivity (predicted no M-coupling) : 28.2 dBi
- Beamwidth: 7.7 deg

Ka-Band Phased Array System Characterization Task

PI: Roberto Acosta

Description and Objectives:

- Demonstrate flight worthiness of the newly acquired GRC 256 element Ka-Band phase array antenna system in the laboratory environment.
- To accurately determine the directivity, gain, eirp, and pattern as a function of scan angle up ± 60° of the Boeing PA.
- Resolve any differences between Boeing characterization and GRC characterization of the array, if any are detected.

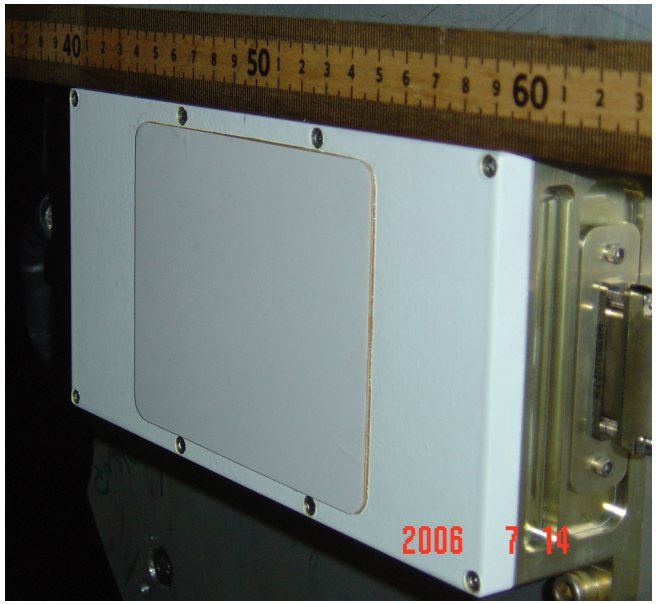
Approach:

- Test array antenna EIRP as function of scan angle for two polarizations over the band of operation. (e.g., lower, mid and high band frequency).
- Test array performance using a wideband modem (up to 650 Mbps) BPSK modulation and determine bit error as a function of scan angle and Eb/N0.
- Test pointing and scanning accuracy by simulating vehicle dynamics in the far-field range.

Partners:

- Daniel G. Baize, Space-Based Range Demonstration & Certification Project Manager, John F. Kennedy Space Center

Accomplishments:



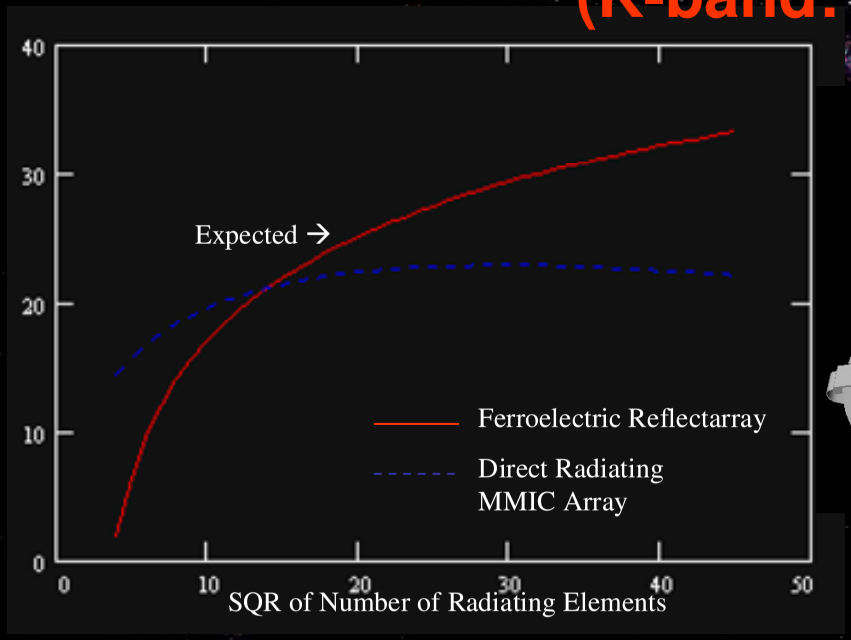
Schedule Milestones FY06/FY07	Status
• Develop test plan	Completed
• Fabricate Laboratory fixtures	Completed
• Antenna CW EIRP	Completed
• Antenna Pattern Characterization	Completed
• Modulation testing	1- 4 - 07
• Vehicle dynamic BER testing	1- 4 -07

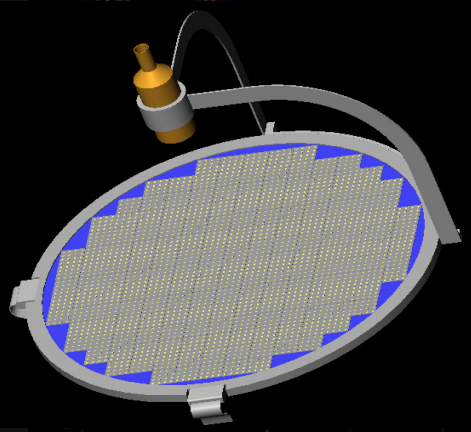
Challenges-Down-converter and up-converter for the dynamic experiment is not complete and parts are required. Modulation test may be delayed to after 1 - 4 - 07 because of procurement of parts.

(Originally (FY 02-04) sponsored SOMD now (FY07) CTN (formerly ECANS) is the sponsor)

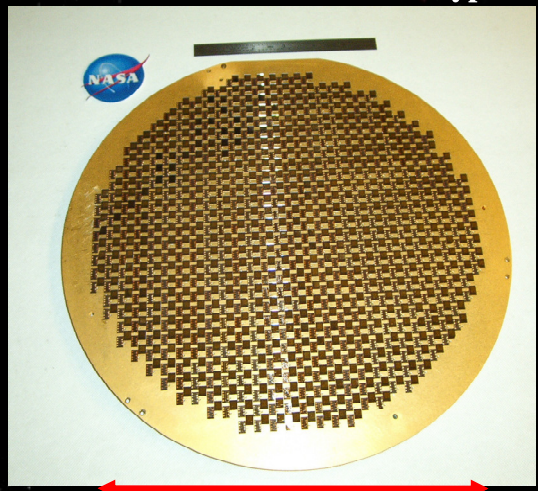
Ferroelectric Reflectarray Development

(K-band: TRL 3)

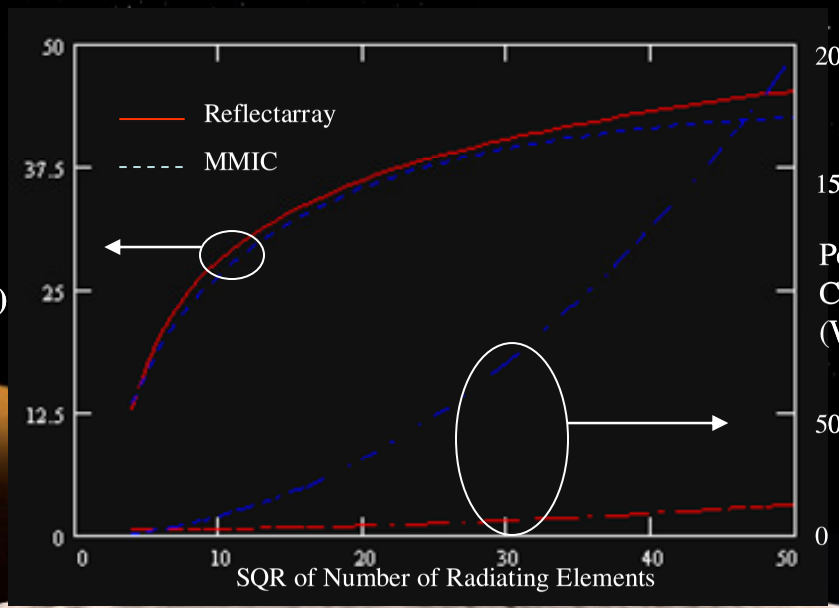




19 GHz 615 Element Prototype

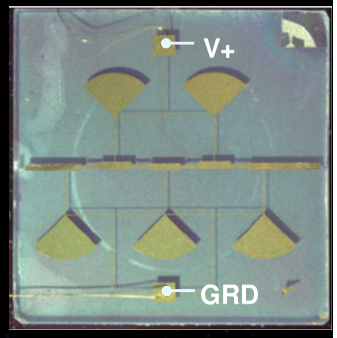


≈ 28 cm Active Diameter



Benefits

- High efficiency
- Zero manifold loss
- Electronically steerable
- Lightweight, planar reflector



Potential Applications

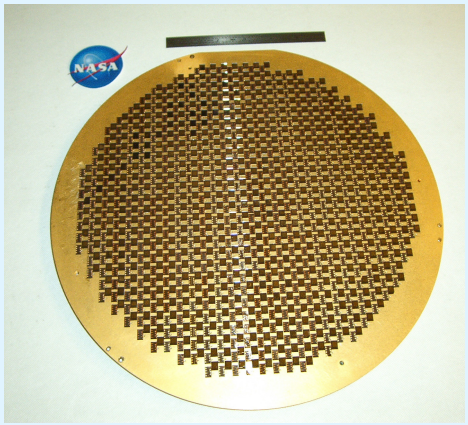
- Satellite Antenna Systems
- Ground-based Deep Space Network Array

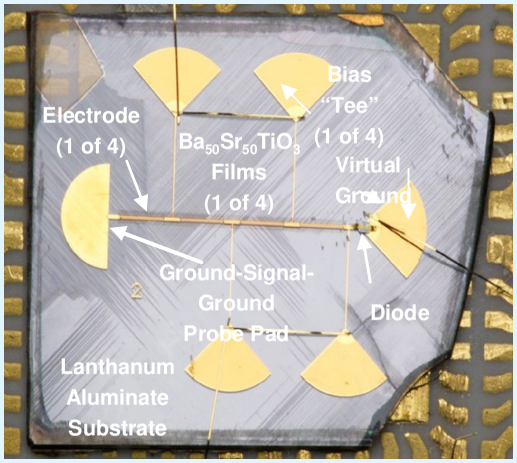
Ferroelectric Scanning Reflectarray Antenna

PI: Robert Romanofsky

Description and Objectives:

- Develop an antenna concept combining the best features of a gimbaled parabolic reflector (high efficiency and relatively low cost) and a scanning phased array antenna (agile, vibration-free beam steering)
- Design a low cost, high efficiency scanning reflectarray antenna based on thin ferroelectric film phase shifters
- Develop "manufacturable" processes and team with small businesses so that the technology can be commercialized
- Design the technology to be consistent with the rigors of space flight for an eventual space experiment
- Challenges:
  - Low Loss Phase Shifters (< 3 dB)
  - Ferroelectric Film Cost
  - Low Power/Fast controller





Approach:

- Devise low loss phase shifters (coupled-line, synthetic line, hybrid, slot-line, etc.) based on thin ferroelectric films
- Demonstrate a prototype scanning reflectarray and controller at K-band
- Analyze techniques to improve efficiency (e.g., non-contiguous ground plane) and reduce cost (e.g. flip-chip films)
- Conduct theoretical development of wideband array and self-modulating array
- Develop space-qualifiable Ka-band array and controller

Co-I's / Partners:

- Zin Technologies
- Mound Laser Photonics Center
- Neocera

Milestones and Schedule:

	Target	Status
• 615 element K-band prototype	'05	Repair by 4th qtr 06
• 2.5 dB Loss X-band phase Shifter	3rd Qtr05	Completed 3rd Qtr 05
• Ka-band reflectarray + fast controller	4th Qtr 07	
• Space qualifiable reflectarray	4th Qtr 08	
• Self-Modulating Space FRA	2nd Qtr 10	

Application / Mission:

- Mars Relay satellite large aperture articulated feed
- Lunar and Mars polar orbiting satellites
- Earth LEO science and communications satellites
- Space interferometry missions intolerant of vibration

$TRL_{in} = 3$
$TRL_{out} = 5$

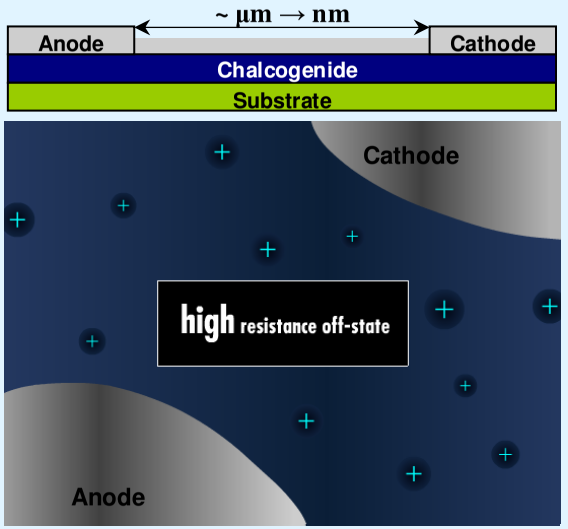
Nano-electrochemical Switch for Phased Arrays

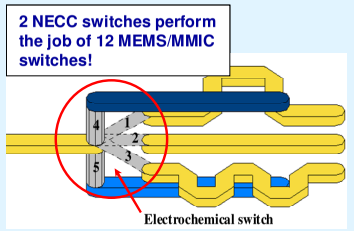
PI: James Nessel

Funding Source: IR&D FY06

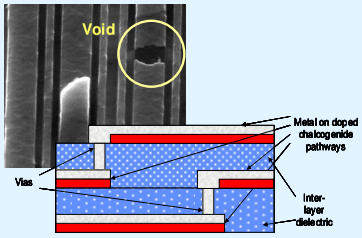
Description and Objectives:

- Ag+ ions dissolved into chalcogenide glass possess high ion mobilities over short distance scales. Reduction of Ag+ ions by a small applied voltage (~0.3V) forms Ag metal which forms physical connection between electrodes (ON). A reverse bias of equal and opposite magnitude oxidizes Ag to force return to Ag+ ion state (OFF).
- Investigate microwave performance of electrochemical-based technology (e.g., frequency response, insertion loss, isolation).
- Develop candidate switch designs that best exploit microwave performance of chalcogenide materials. The switch will form the basic building block for technology insertion in reconfigurable RF applications.
- Design and develop a low loss, cost-effective discrete phase-shifter utilizing this technology, and demonstrate an integrated phase-shifter and antenna array system.





4-bit Switchline Phase Shifter



Self-Healing Circuitry

Approach:

- Leverage Arizona State University's clean room facilities and fabrication experience with this material to enable rapid prototyping of nano-electrochemical switch designs.
- Utilize GRC Microwave Systems Laboratory to perform RF characterization of novel switches.
- Upon successful completion of first year effort, substantial investment in in-house fabrication tools during Phase II.
- Investigate other potential areas both within and outside of NASA for technology insertion.

Co-I's / Partners:

Dr. Richard Lee (GRC/RCA)

Dr. Carl Mueller (ANALEX/RCA)

Dr. Michael Kozicki (ASU)

Milestones and Schedules:

FY06: Fabrication of prototype nano-electrochemical switches

FY07: Demonstration of phase shifter device implementing nano-electrochemical switch

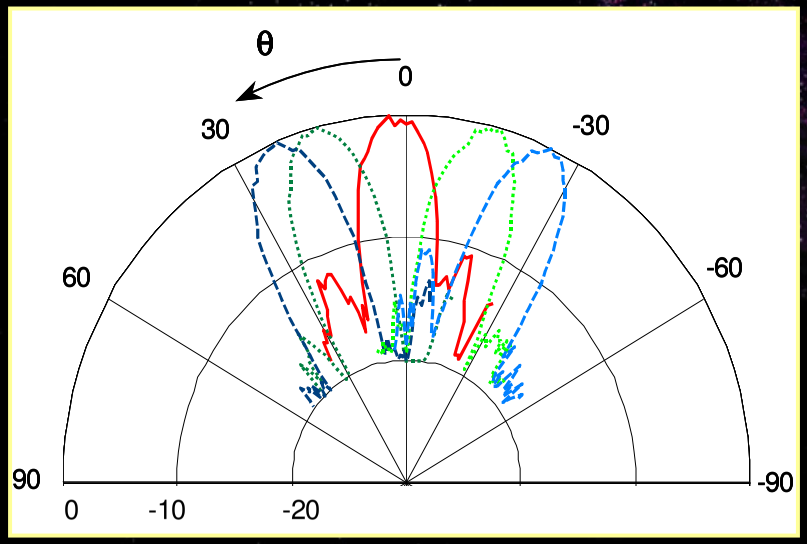
FY08: Integration and test of phase shifter with linear array antenna

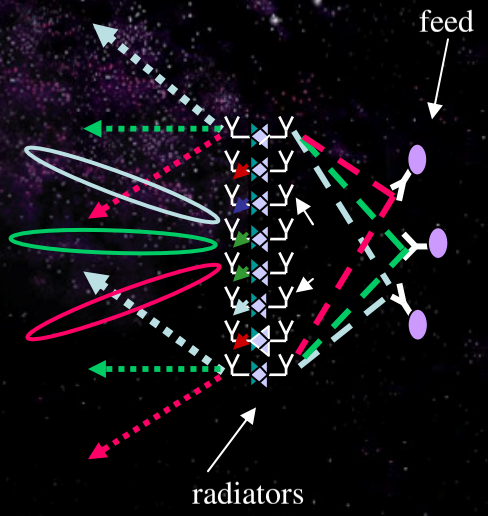
Application/Mission:

- Phase shifters utilizing this technology could potentially result in lightweight, low power, cost-effective beam-steerable phased arrays for communications, navigation, and surveillance.
  e.g., SOMD-SCDS/ESMD
- Material-dependent operation allows for unique device implementation which inherently reduces susceptibility to failure (applicable to many areas throughout the Center)
  e.g., Materials/Sensors/Nanotechnology Lab

Multi-Beam Antennas

(S-, Ka-band: TRL 4)



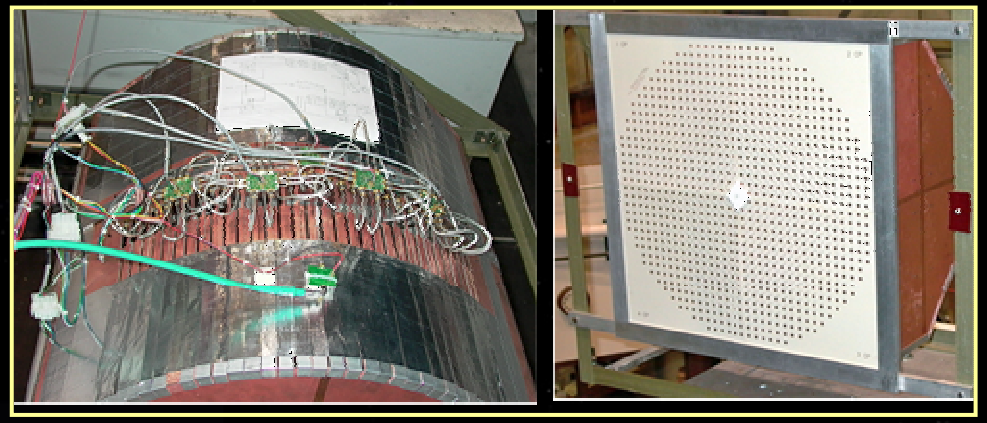


Benefits

- No manifold losses
- Capable of multiple beams
- Pseudo conformal

Potential Applications

- Smart Antenna Systems
- Ground-based Communications (*i.e.*, Habitat, Relays)
- Satellite Constellations



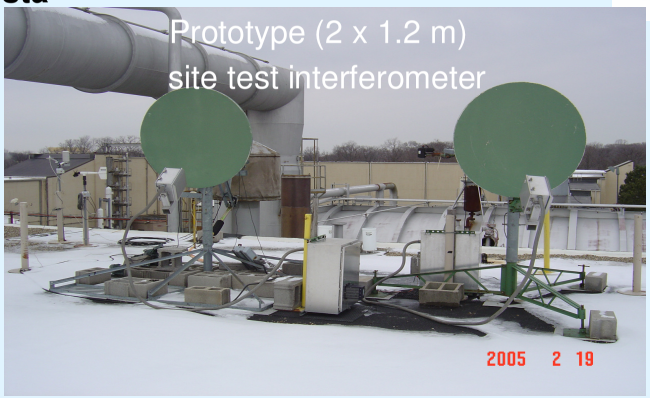
Collaboration with Dr. Z. Popovic University of Colorado, Boulder

GRC Ka-Band Atmospheric Calibration Task

PI : Dr. Roberto Acosta

Description and Objectives:

- ***Statistical characterization*** of the *path length fluctuations* at candidate sites for future distributed ground based antenna systems operating at Ka-Band (e.g., Next Generation Deep Space Network)
- ***The objective*** is to improve the understanding of atmospheric effects on widely distributed Ka-band systems at current and future NASA potential operational sites.
  - **Attenuation Statistics (High Availability)**
  - **Path Length Fluctuations Statistics**
  - **Advanced Calibration Techniques.**



Approach:

- ***In-house (GRC) development*** of a prototype (2 x 1.2 m) site test interferometer (STI).
- ***Statistical one year data collection*** of the path length fluctuations.
  - Site test interferometer to receive an unmodulated beacon at 20.2 GHz, broadcast from a geostationary satellite (ANIK F2).
  - The measured *path length fluctuations* data (Frequency = 20.2 GHz, Elevation angle 38 degrees and a Baseline separation of 250 m) can be transformed to the actual operating array frequencies, elevation angles, and baselines.

Co-I's / Partners:

- **David Morabito and Larry D'Addario**, JPL (Co-Investigators)
- **JPL/ITT Industries (Goldstone)**

Milestones and Schedule:

• Design and Fabrication of STI Prototype	05-31-06
• Laboratory Test of STI Prototype	09-29-06
• GOLDSTONE Site Survey	09-11-06
• Site Requirement Document	09-11-06
• Installation of STI Prototype at GOLDSTONE	02-19-07
• Data Collection Start	03-01-07
• De-Installation of STI Prototype at GOLDSTONE	03-02-08

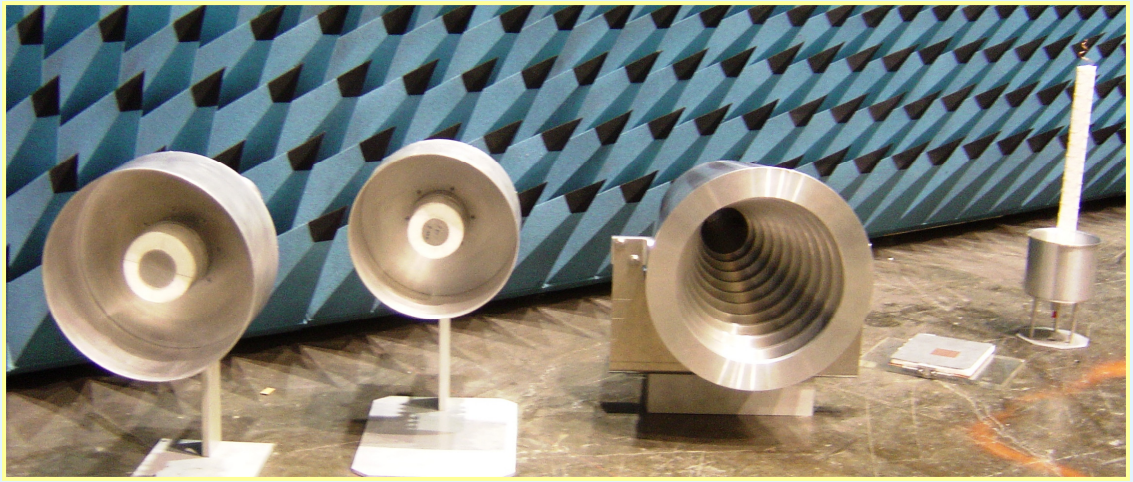
Application / Mission:

- Widely Distributed Ground Based Ka-Band Systems for supporting **SOMD, SMD and ESMD** enterprises.

TDRSS-C Antenna Development

(S-band: TRL 4)

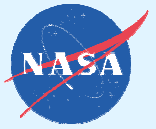
- Next generation TDRSS to implement beam forming between S-band Single Access and Multiple Access antennas
- GRC responsible for antenna element design, construction and characterization of candidate antennas for next generation Multiple Access phased array



Specification	Bandwidth 2.0 – 2.3 GHz WB 2.2 – 2.3 GHz NB	Directivity >15 dBi Peak	Directivity at ± 20 deg. > 10 dBi	Axial Ratio < 5 dB ± 20 deg. LHCP,RHCP	Pol. Isolation < -20 dB	Return Loss < -20 dB Port Isolation < -10 dB	Mounting Footprint (Diameter)
Cup-Waveguide (Wideband)	NB Meets WB MEETS	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	Meets 11.5 in
Cup-Waveguide (Narrowband)	NB Meets	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	Meets 10.6 in
Horn	NB Meets	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	DNM* 14.5 in
Helix	NB Meets	Meets	Meets	Meets LHCP	NA	Meets	Meets 6.0 in
Cup-Patch	WB Meets	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	Meets 12.5 in

Potential Applications

- Satellite Antenna Systems



SMALL ANTENNAS
(TRL 1-3)

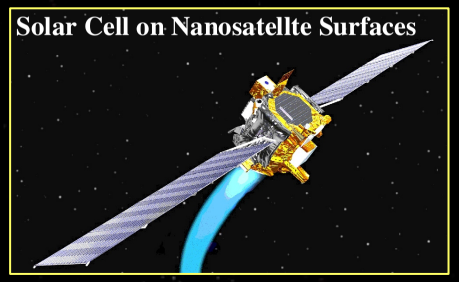
Miniature Antenna Technologies for Future NASA Exploration Missions

Description and Objectives:

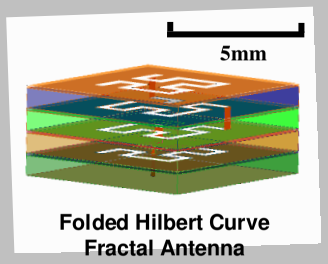
- Develop new design concepts and candidate miniature antenna structures capable of supporting the communication needs of future Lunar and Martian surface exploration activities.
- Develop compact, self-powering, self-oscillating communications package utilizing miniature antenna development effort.
- Perform trade-off studies among in-house miniature antenna designs and state-of-the-art commercial off-the-shelf (COTS) antennas for Exploration Missions.
- Develop processing algorithm for a randomly distributed network of Lunar surface sensors to enable a surface-to-orbit communication without the need of a Lunar surface base station.

Application: Lunar Surface Exploration Missions

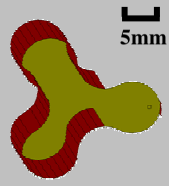
- Robots and Rovers
- Surface Sensors/Probes
- Astronaut EVA
- Nanosatellites



Technology Products:

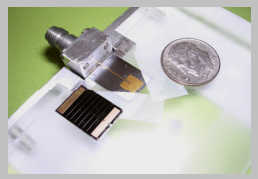


Folded Hilbert Curve Fractal Antenna

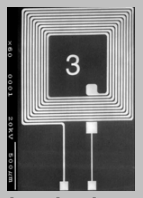


Compact Microstrip Monopole Antenna

$TRL_{in} = 2$
$TRL_{out} = 3$

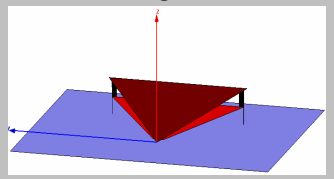


Solar Cell Integrated Antenna

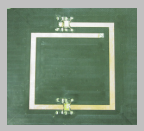


Mininiaturized antenna for Bio-MEMS Sensors

$TRL_{in} = 2$
$TRL_{out} = 3$

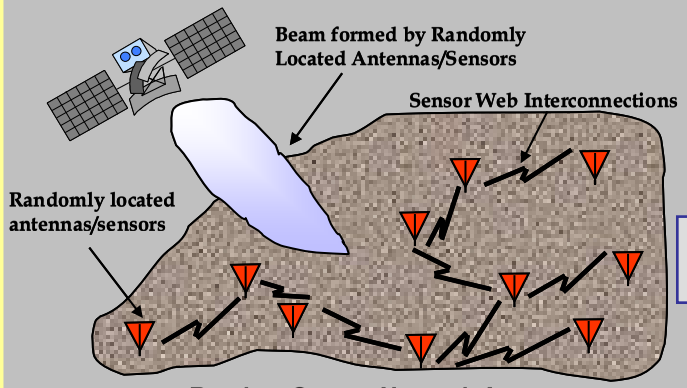


Two-layer Sector Miniature Antenna



MEMS Integrated Reconfigurable Antenna

$TRL_{in} = 2$
$TRL_{out} = 3$



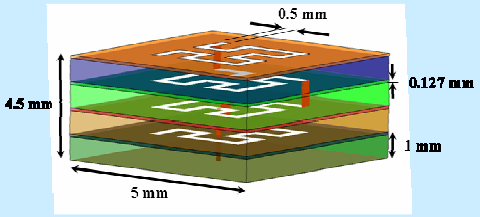
Random Sensor Network Array

$TRL_{in} = 2$
$TRL_{out} = 3$

folded Hilbert Curve Fractal Antenna (fHCFA)

Design Concept:

- Fractal antenna geometry allows for unique wideband/multi-band operation due to pattern-repetitive nature of fractal shapes. Geometry also allows for antenna miniaturization, similar to meander lines, but with more efficient space utilization.
- Develop an antenna based on a 3rd order Hilbert curve geometry folded upon itself (multilayer) to further decrease antenna footprint.



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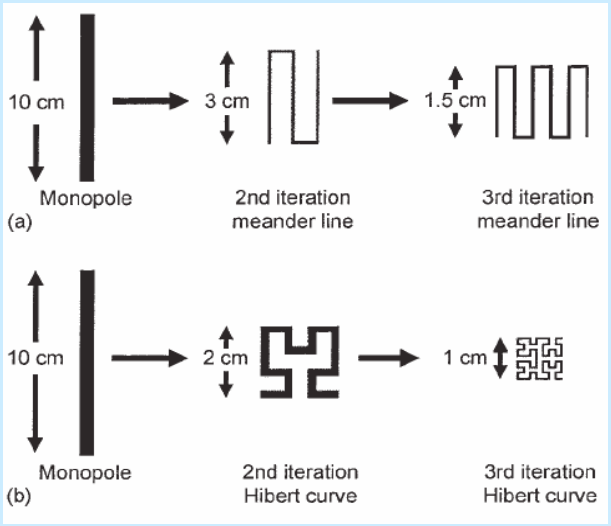
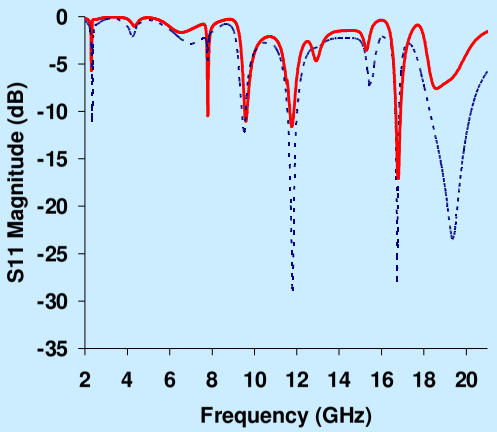
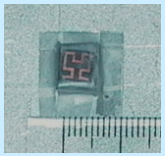


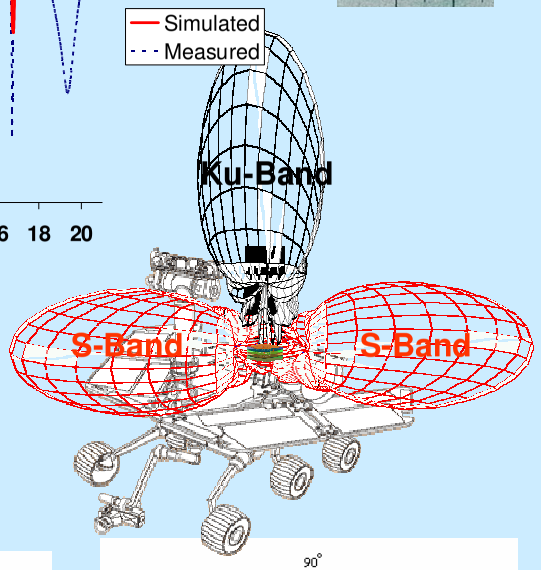
[1] James A. Nessel, Afroz J. Zaman, Félix A. Miranda, "A Miniaturized Antenna for Surface-to-Surface and Surface-to-Orbiter Applications," Microwave and Optical Technology Letters, Vol. 48, No. 5, May 2006, pg. 859-862

Results:

- fHCFA exhibits multi-resonant behavior.
- Two modes of operation with optimized radiation pattern diversity for surface-to-surface and surface-to-orbit communications at relevant frequencies without switching.







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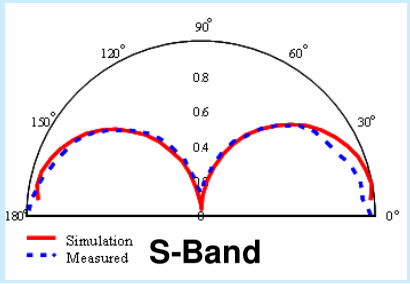
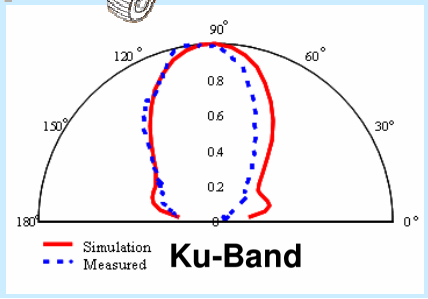
TRL $_{out}$ = 3



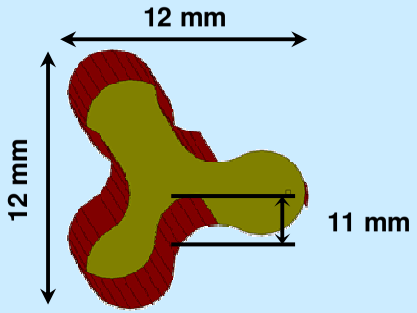


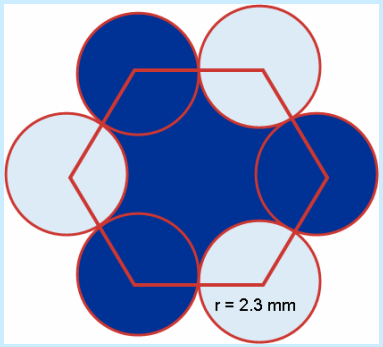
Compact Microstrip Monopole Antenna (CMMA)

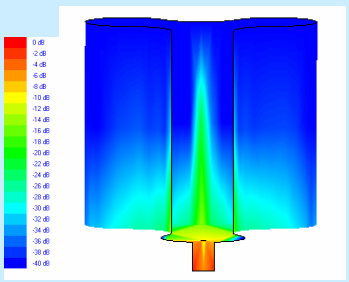
Design Concept:

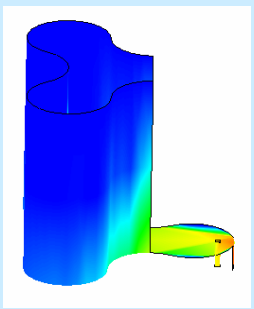
- Reduce operating frequency of patch antenna through use of grounding wall and increased perimeter with a compact footprint.
- Adjust for inherent decrease in directivity with vertical wall.
- Combine a microstrip patch with a 3-dimensional structure to attain a highly directive, broadband, compact antenna which radiates like a miniature monopole antenna.

< λ/12 !



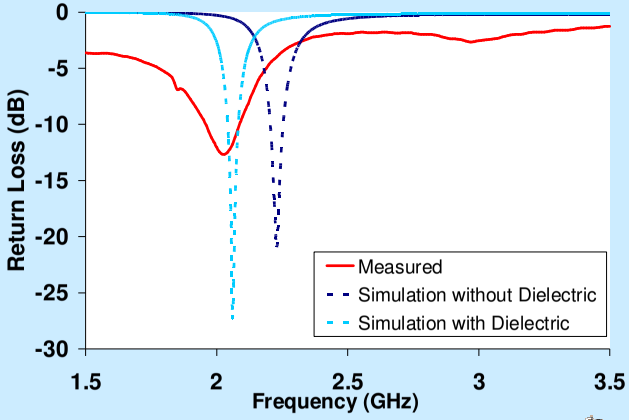


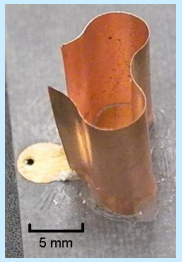


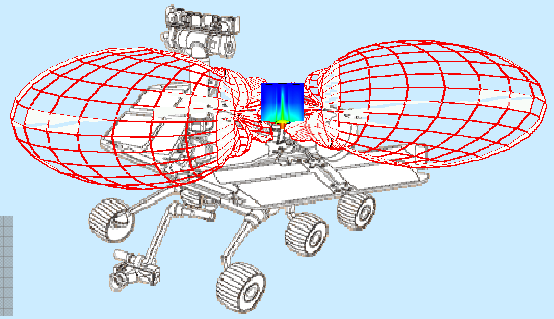


Results:

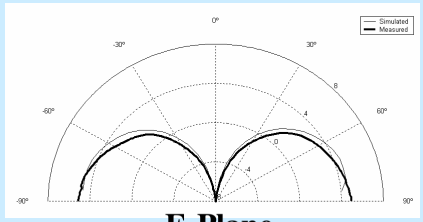
- End-fire radiation pattern allows for lunar surface-to-surface communications with an antenna structure 1/6th the size of a monopole antenna.



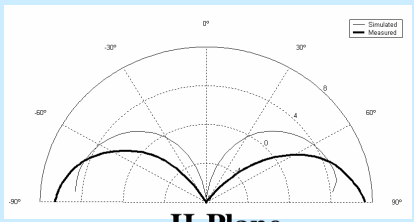




TRL $_{in}$ = 2
TRL $_{out}$ = 3



E-Plane



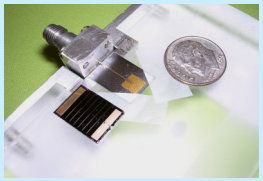
H-Plane

[2] Philip Barr, Afroz Zaman, Félix Miranda, "A Compact, Broadband Antenna for Planetary Surface-to-Surface Wireless Communications," Microwave and Optical Technology Letters, Vol. 48, Iss. 3, March 2006, pg. 521-524

Solar Cell Integrated Antennas

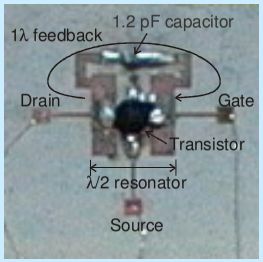
Design Concept:

- Integrate solar cell, local oscillator and miniature antenna for complete, compact, self-powering communications system.
- Integrated antenna radiating element/oscillator generates it's own RF power.
- Demonstrate prototype active oscillator solar cell array antenna modules capable of beam steering based on multi-junction GaAs solar cell and oscillator antenna technologies.
- Foundation for larger aperture, beam-steerable antennas using coupled oscillator approach.
- The proposed system will enable the development of low-cost, lightweight satellites with high directivity communication links for Flexible Access Networks.



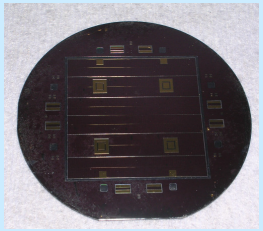
Miniature Antenna

Provides compact structure to transmit RF signal



Local Oscillator

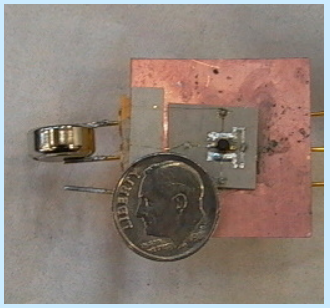
Provides modulation of frequency carrier for relevant data transmission



Solar Cell

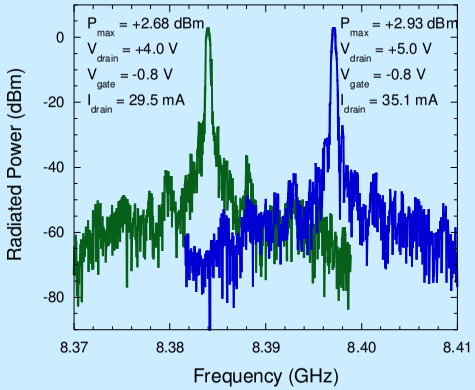
Provides power for communications system. Can be integrated on antenna layer, or on oscillator layer.

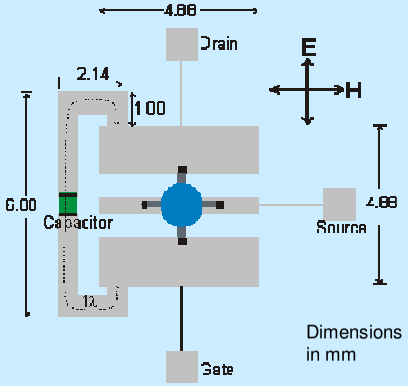
Results:

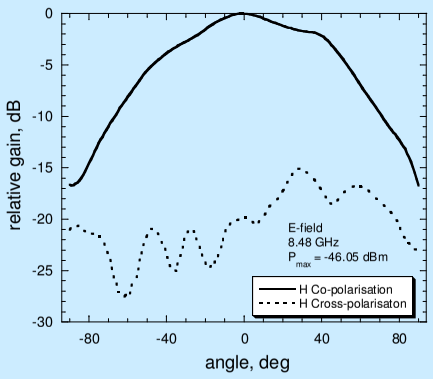


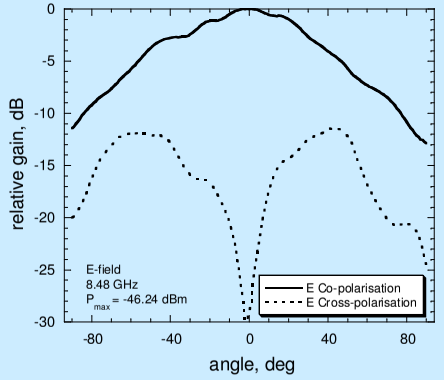
Fabricated integrated antenna/oscillator using Duroid RT 6010 microwave laminate (dielectric constant = 10.2), with pseudomorphic high electron mobility gallium arsenide transistors

$TRL_{in} = 2$
$TRL_{out} = 3$







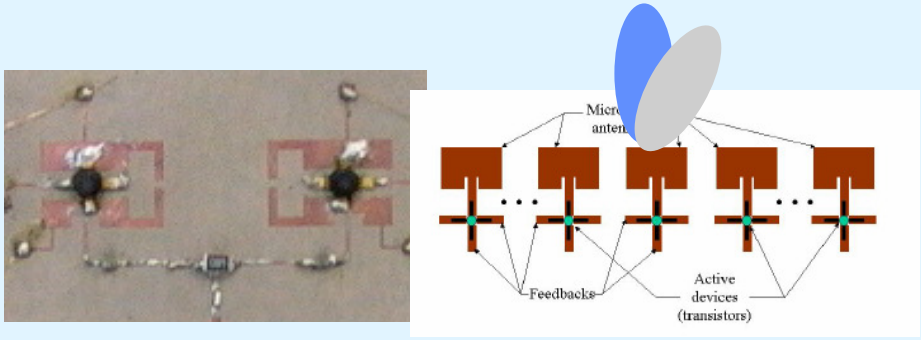


Beam-Steerable Active Integrated Antennas (AIA)

PI: Richard Q Lee

Description and Objectives:

- Develop a highly efficient, coupled local oscillator array based on SiGe/Si on sapphire modulation doped field effect transistor technology.
- Perform low TRL development of highly integrated, beam-steerable AIAs that utilize coupled local oscillators in the beam generation and beam-steering circuitry.
- Develop a modular approach to the construction of AIAs



Oscillator arrays

Approach:

- Grow n-MODFET SiGe/Si device structures on sapphire.
- Fabricate transistors with gate lengths of 2 µm or greater.
- Demonstrate single oscillator coupled antenna element
- Design, fabricate and test prototype 1x2 passive antenna array
- Integrate SiGe/Si on sapphire transistors into 1x2 antenna array.
- Demonstrate 1x2 oscillator coupled active array antenna

Co-I's / Partners:

– Carl Mueller, George Ponchak

Milestones and Schedules:

- A single-element AIA have been designed and tested
- Injection locking in a 2 element array has been demonstrated.
- A Scheme for modulating the AIA and maximizing the bandwidth of the antenna has been formulated.
- A mask set containing SiGe/Si on sapphire transistors with improved RF and optimal 1/f noise performance for a single-element AIAs has been designed.

Application/Mission:

Potential applications include NASA planetary exploration missions to the Moon and Mars

MPC-based Miniature Antennas

(TRL 2)

- **Artificially manufacturable Metamaterials: Magnetic Photonic Crystals (MPC).**
- **These MPCs exhibit the following properties:**

(a) considerable slow down of incoming wave, resulting in frozen mode.

(b) huge amplitude increase.

(c) minimal reflection at the free space interface.

(d) large effective dielectric constant, thus enabling miniaturization of the embedded elements

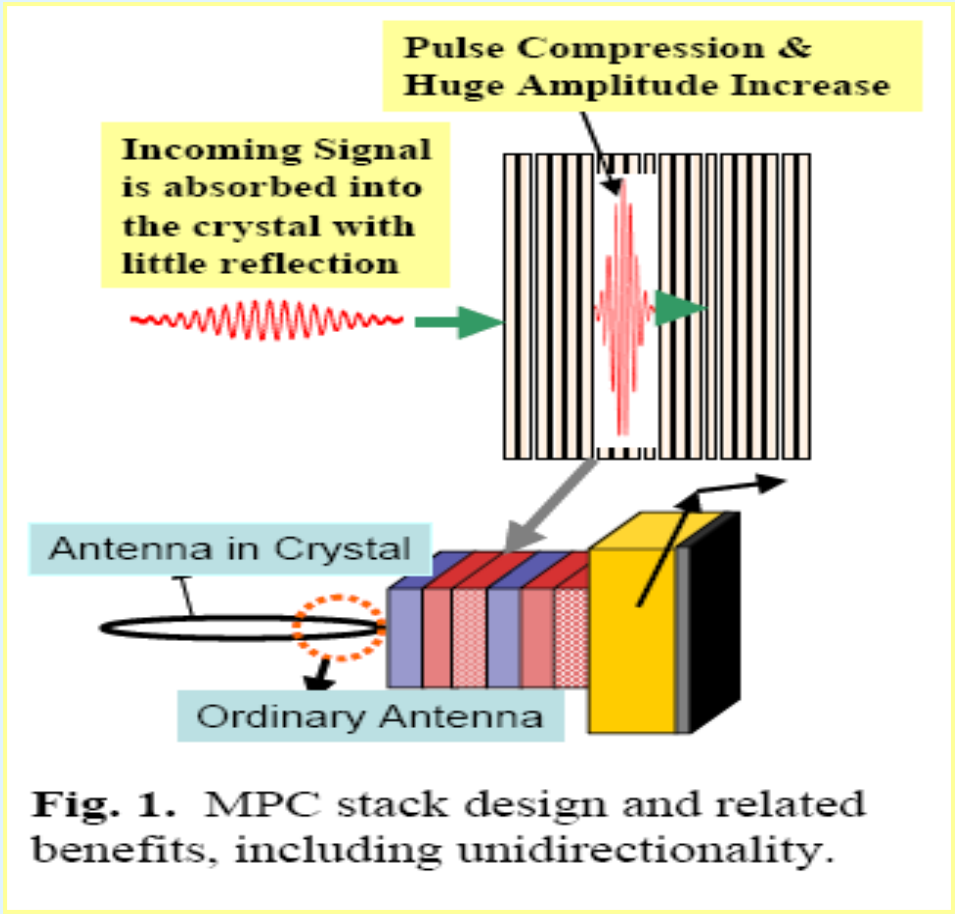


Fig. 1. MPC stack design and related benefits, including unidirectionality.

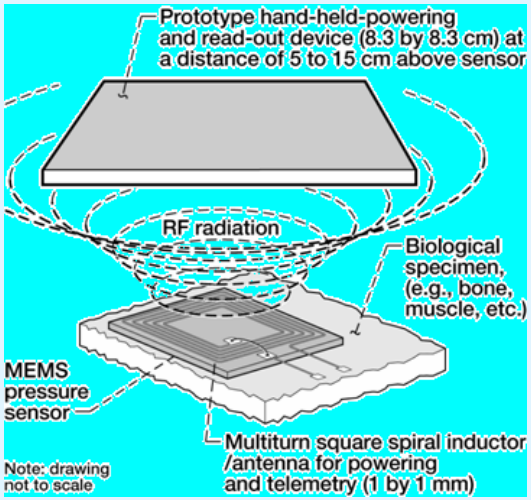
Collaboration with Dr. John Volakis and Mr. Jeff Kula (OSU)

National Aeronautics and Space Administration

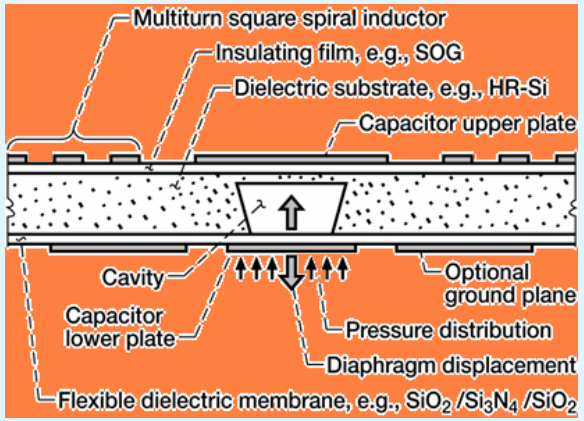
RF Telemetry System for Implantable Bio-MEMS Sensors

(TRL 3-4)

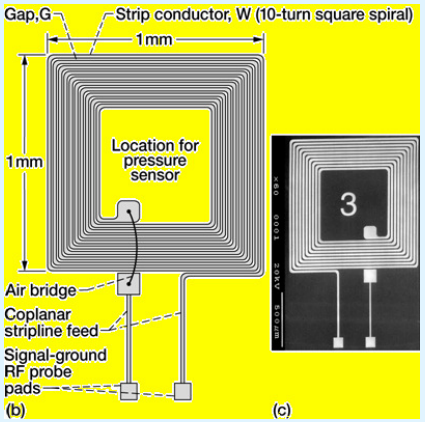
- **NASA seeks to develop telemetry based implantable sensing systems to monitor the physiological parameters of humans during space flights**
- **A novel miniature inductor and pick-up antenna for contact-less powering and RF telemetry from implantable Bio-MEMS sensors has been developed.**



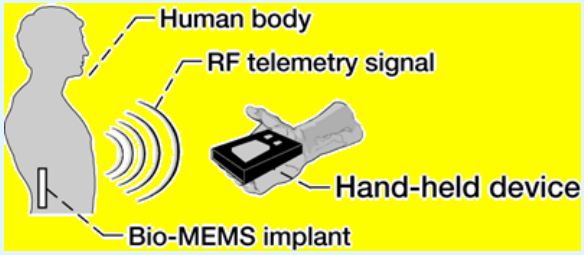
Contact-less powering and telemetry concept.



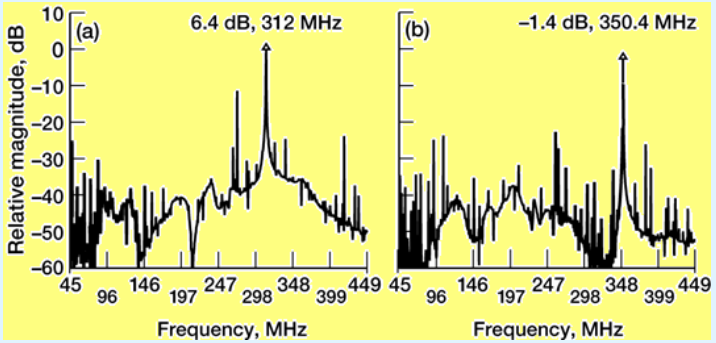
Schematic of a capacitive pressure sensor.



Schematic of miniature spiral inductor on SOG/HR-Si wafer and Photomicrograph of inductor/antenna.



Contact-less powering and telemetry application in biosensors.



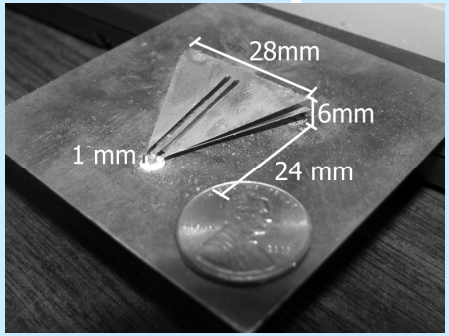
Measured received relative signal strength as a function of frequency.
(a) Pick-up antenna at a height of 5 cm. (b) Pick-up antenna at a height of 10 cm.

Miniaturized Antennas in Random Sensor Arrays for Planetary Surface Exploration

PI : Dr. Jennifer Bernhard/Univ. of Illinois

Concept:

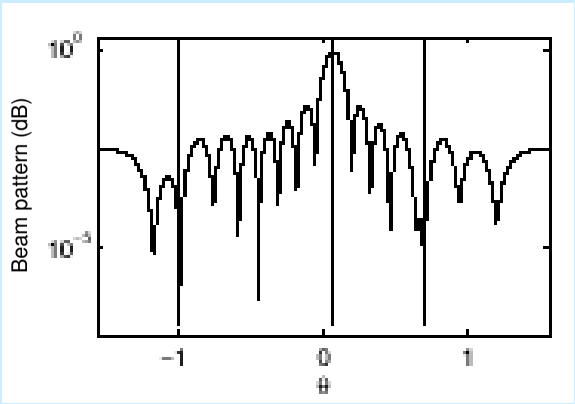
- Develop electrically small antennas and self-healing, adaptive decision algorithms for coherent signal detection and transmission from an array of randomly distributed planetary sensors. The sensor array will configure itself to form a beam in a general direction that can be intercepted by a passing orbiter or directed to a particular satellite or planetary surface-based receiver.
- Develop miniaturized antennas and beam forming algorithm for random sensor arrays that enable the sensor to work together to communicate their data to remote collection sites without the need for a base station
- Develop miniaturized antennas with moderate bandwidths for planetary surface communications between remote sites sensors or orbiters.
- The technology is intended to enable low-risk sensing and monitoring missions in hostile planetary and/or atmospheric environments.
- Development of distributed Bayesian Algorithm based fault tolerant, self organizing random sensor detection



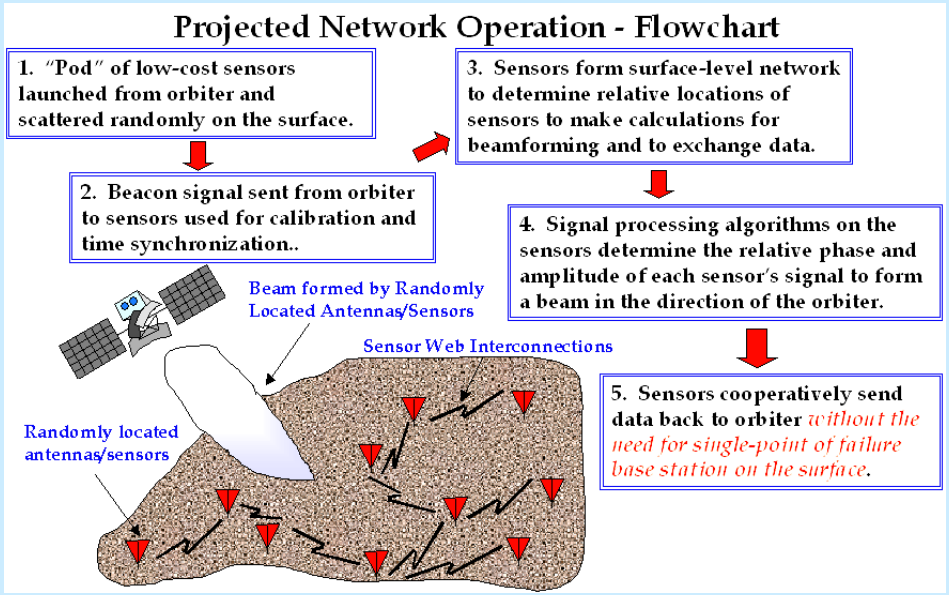
Prototype Miniaturized Antenna

TRL $_{in}$ = 2
TRL $_{out}$ = 3

Approach allows randomly distributed Lunar surface sensors to work together as an array and thus enhances communication capabilities by decreasing the probability of single point communication failure.



Simulated Beam forming Achieved Using Bayesian Estimation Method For a Random Sensor Array



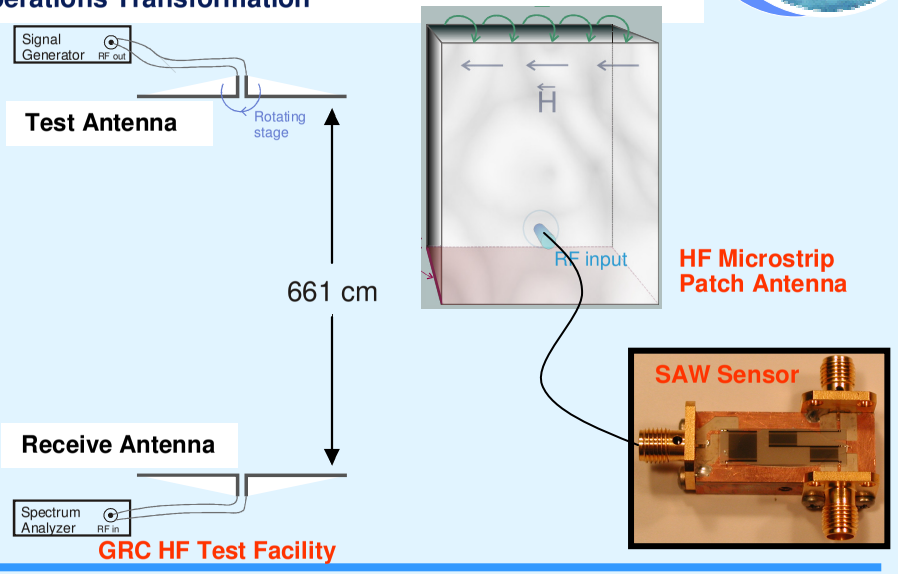
High Frequency (HF) Passive Sensor Antennas

PI: Félix A. Miranda

Funding Source: Space Operations Transformation

Description and Objectives:

- Small, conformal High Frequency (HF) antennas operating at 70 MHz are desired for integration with Surface Acoustic Wave (SAW) sensors for wireless data acquisition in lunar exploration activities (e.g., lunar habitats, ISS).
- To design and develop prototype antennas that meet the following criteria:
  - 70 MHz center frequency operation
  - 1% 2:1 VSWR bandwidth
  - Omnidirectional radiation pattern
  - Vertical Polarization
  - 10 meter range
- To demonstrate functional operation of embedded antenna in a relevant environment.



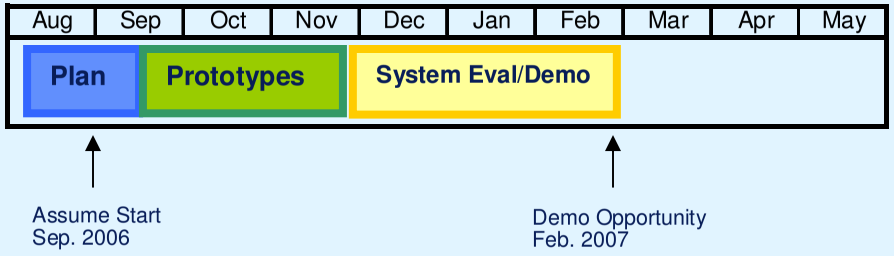
Approach:

- Develop and verify operation of VHF antenna metrology testbed to adequately characterize prototype antennas.
- Construct and characterize a ½ wavelength dipole antenna (70 MHz) to identify operational baseline requirements.
- Simulate electrically small antenna designs using advanced electromagnetic simulation tools (i.e., Ansoft HFSS, Zeland IE3D)
- Construct and characterize performance of potential antenna designs in a relevant environment.

Co-I's / Partners:

Félix Miranda (GRC\RCA)
James Nessel (GRC\RCA)
Carl Mueller (ANALEX\RCA)
Patrick Fink (JSC)
Timothy Kennedy (JSC)

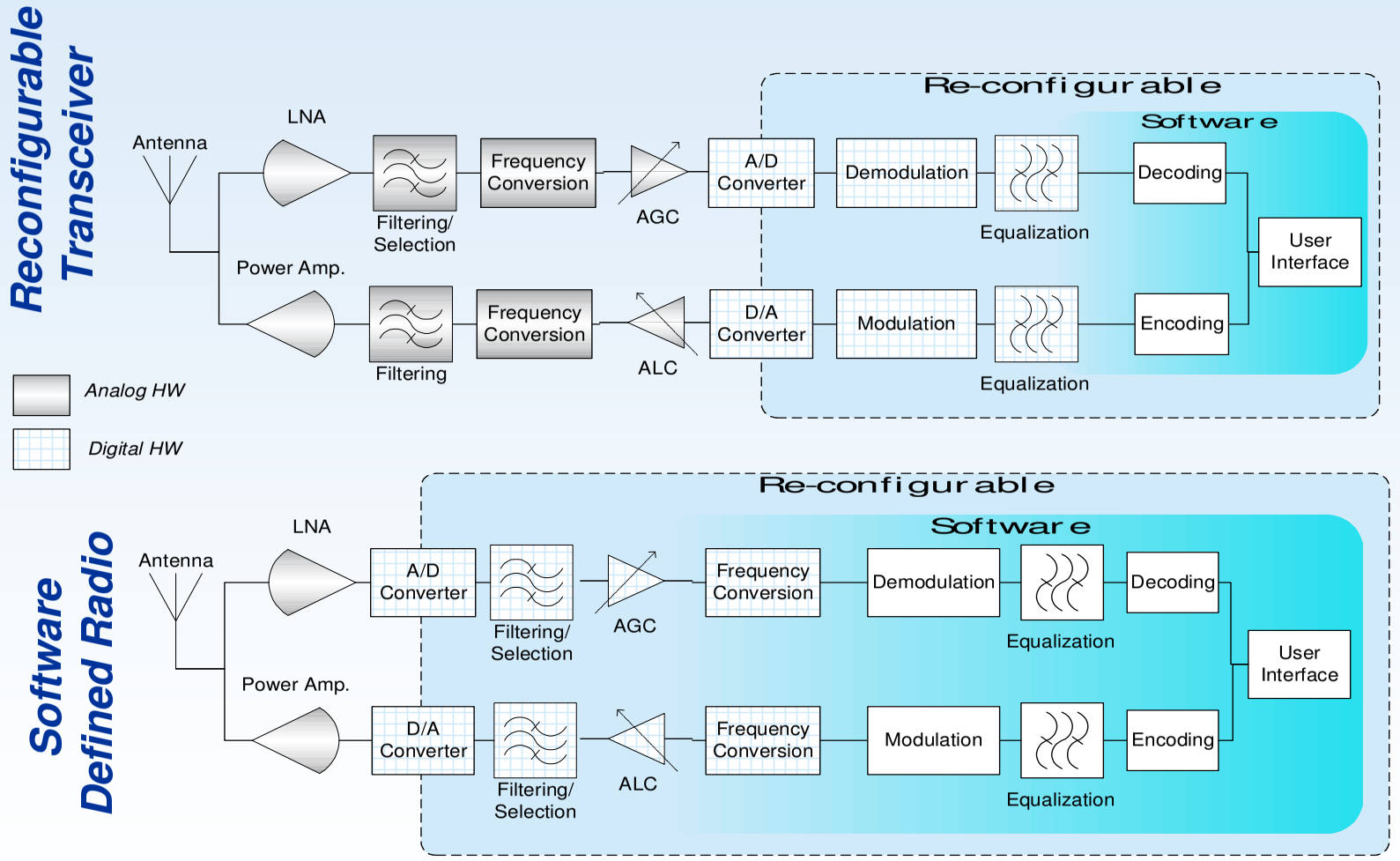
Milestones and Schedules:



Application/Mission:

- Embedded SAW sensors with wireless connectivity would allow for prolific sensor web systems in a lunar or space-based habitat to accurately and efficiently detect micro-meteroid impacts and enhance mission safety (ESMD)

Reconfigurable Transceivers and Software Defined Radios are the Future of Telecommunications



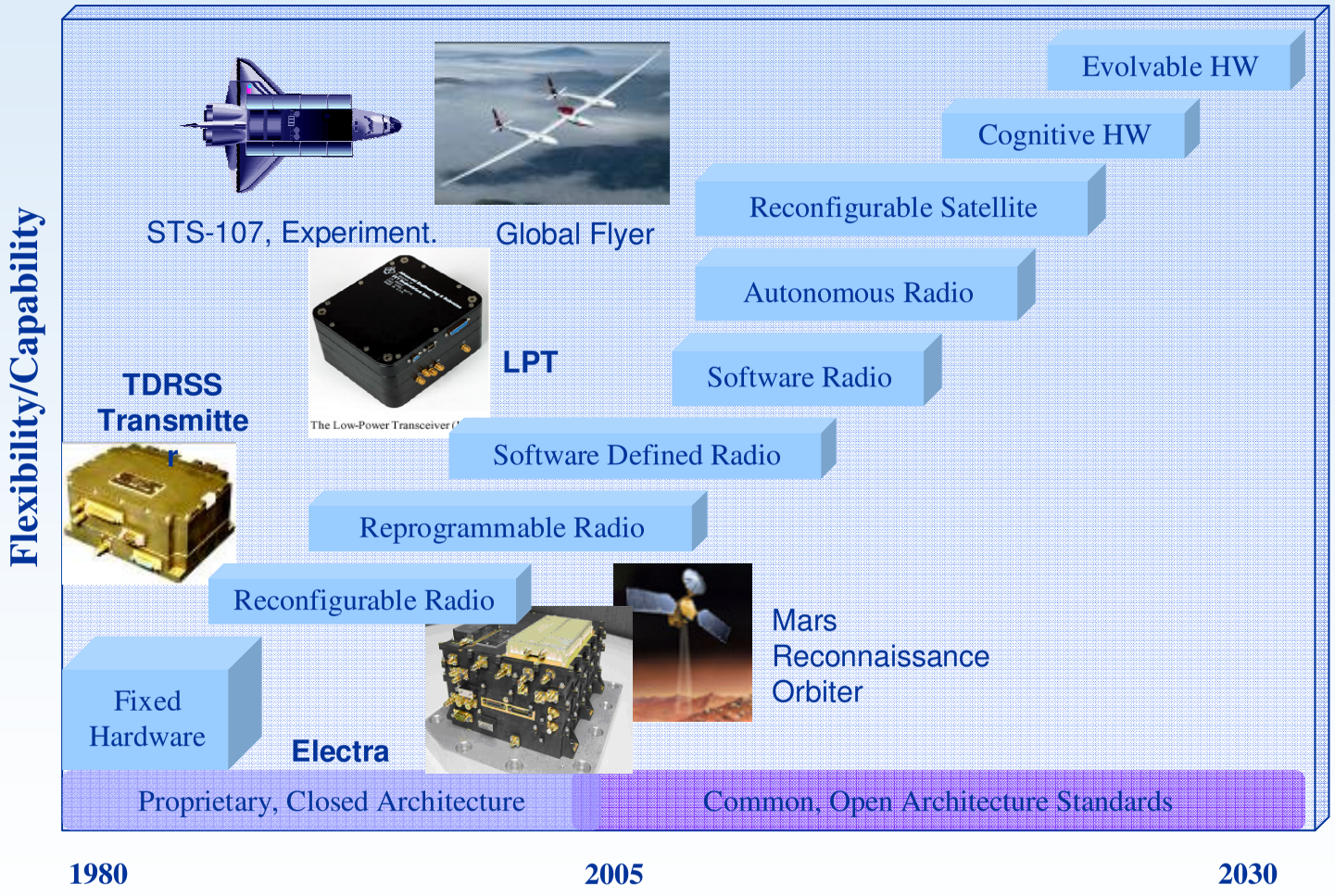
SDR's and The Space Telecommunications Radios System (STRS) Architecture

- Reconfigurable SDR will enable new mission concepts
  - Remote/autonomous operations
  - Future cognitive radios

- STRS Architecture provides commonality among reconfigurable SDR developed by NASA
  - Provides a coordinated method across the agency to apply SDR technology
  - Program/mission risk reduction
  - Adjusts to evolving requirements
  - Allows technology infusion
  - Reduces vendor dependence

- STRS Architecture recommended as Agency Standard - will evolve before becoming a standard
  - Waveform Control
  - Navigation, Security, Networking…
  - Leverage best aspects of DoD's JTRS SCA and industry practice
- Exploration Vision will present opportunities to apply SDR

Programmable Technology Progression

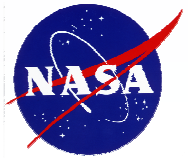


Advanced Extra Vehicular Activity Space Suit Communications

Glenn Research Center

Communications Division

at Lewis Field



Advanced Extra Vehicular Activity (AEVA) Space Suits

CEV Launch, Return and Contingency EVA Suit

Flight Suit	In-Space Suit	Surface Suit

Communications, Avionics and Informatics Enabling Technologies

AEVA Research Tasks

EVA INFORMATION SYSTEMS

- Develop an EVA suit information system prototyping platform which integrates displays, voice interfaces, computers, sensor systems, and software for evaluation of advanced EVA Information System concepts.
- Applications include: Voice recognition for command and control of an on-suit computer; tracking and monitoring of suit life support consumables; displaying timeline procedures and check-off of tasks; displaying crew biomedical information for pacing of work activities; and navigation and tracking for surface operations.

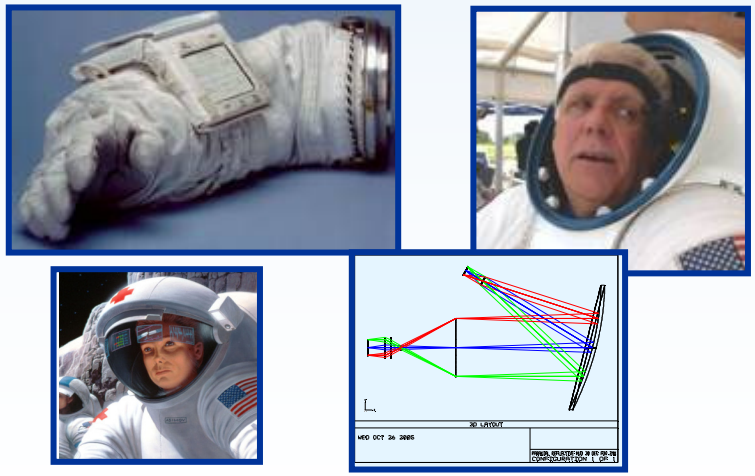
EVA SENSOR SYSTEMS

- Develop sensor system that promotes autonomous crew performance and health monitoring such as heart rate and metabolic rate determination.
- While Apollo era metabolic rate was calculated on the ground, future EVA systems need the ability for autonomous operation.
- Sensor system includes development of reduced size, power, and mass CO2 sensors.

AEVA Research Tasks

EVA DISPLAY SYSTEMS

- Investigate helmet mounted displays initially and expand to cuff mounted displays if HMD proves infeasible; concept and design evaluation (including human factors evaluation) prior to prototype feasibility.
- HMD system will be helmet-mounted, eliminating the need for the crewmember to wear any head gear, which is susceptible to misalignment during EVA. System design must allow for the required low volume, power, and safety concerns for inclusion within EVA helmet.



AUDIO LAB AND DSP VOICE INTERFACE

- Developed for precise characterization of in-suit acoustics and evaluation of forward and return speech channels for prospective and operational systems.
- Develop helmet-mounted audio system to elimination of communications carrier assembly (i.e. “Snoopy cap”.)
- Laboratory supports evaluation of speech quality through creation of utterance database for jury testing as well as objective evaluation of speech quality using ITU-recommended algorithms.

Conclusions

- By 2030, 1 Gbps deep space data rates desired. Choosing the proper antenna technology for future NASA exploration missions will rely on: data rate requirements, available frequencies, available space and power, and desired asset-specific services. Likewise, efficiency, mass, and cost will drive decisions.
- Viable antenna technologies should be scalable and flexible for evolving communications architecture.
- Enabling antenna technologies include: large aperture deployable/ inflatable antennas (reduce space/payload mass), multibeam antennas (reduce power consumption), reconfigurable antennas (reduce space), low loss phased arrays (conformal/graceful degradation), and efficient miniature antennas (reduce space/power).
- Efficient miniature antennas will play a *critical* role in future surface communications assets (e.g., SDR radios) where available space and power place stringent requirements on mobile communications systems at the envisioned UHF/VHF/S-band surface comm. frequencies (i.e., astronaut suits, probes, rovers)